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A RE-EXAMINATION OF THOREAU'S "WALDEN"

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INTRODUCTION

"WHEN we regard Thoreau simply as an observer or as a natural historian," says Burroughs (1), "there have been better, though few so industrious and persistent. He was up and out at all hours of the day and night, and yet he saw and recorded nothing new. It is quite remarkable.... He has added no new line or touch to the portrait of bird or beast that I can recall.... He had not the detective eye of the great naturalist.... To the last, his ornithology was not quite sure, not quite trustworthy."

In this paper I propose to show that, however untrustworthy Thoreau's ornithology may have been, his contribution to at least one natural science, limnology, was original and genuine.

The bulk of Thoreau's limnological observations are set down in *Walden*, although some very important material is confined to his *Journal* and remained unpublished until long after his death. These notes, like his other records of natural history, are fragmentary and discursive, conforming to no methodical program of study or presentation. Nevertheless they have a great intrinsic interest for the ecological reader, and a renewed acquaintance with *Walden* prompted a journey to that lake, the results of which are described below.

The field observations were made on August 6, 1939, during a brief holiday from the Biological Survey of Connecticut lakes then being conducted by the Connecticut State Board of Fisheries and Game. The technical and analytical methods used are referred to elsewhere (2). I am deeply indebted to Professor G. E. Hutchinson for invaluable advice and encouragement, for investigating the history of the discovery of thermal stratification, and for the collection of a water sample from Walden Pond on July 16, 1939. My wife, Georgiana Baxter Deevey, rendered indispensable assistance in the field and in the laboratory. Facilities and equipment were generously provided by the Osborn Zoological Laboratory, and acknowledgment is made to the officials of the Rice Institute Library and the Mirabeau B. Lamar Library of the University of Texas for many courtesies. The manuscript has been read by Dr. A. D. McKillop, of The Rice Institute, and by Dr. Henry Seidel Canby, editor of *The Saturday Review of Literature*.

LIMNOLOGY OF WALDEN POND

Location and hydrography

The lake on whose banks Thoreau spent two of the most profitable years of his life (from July 4, 1845 to September 6, 1847) is in the town of Concord, Massachusetts, where he was born. The physiography of the Concord region bears witness to the activity of the Pleistocene ice sheets, as may be seen by inspection of the U. S. Geological Survey topographic map (Framingham quadrangle). Fig. 1, based on part of this map, shows the disorganized stream pattern and abundant undrained depressions so characteristic of a glaci-

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On the Occurrence of Agmatite in the Rogart Migmatite Area, Sutherland : A Study in Granitization

By HSING-YUAN MA

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(PLATE I)

I. INTRODUCTION

AGMATITE was one of the new descriptive terms introduced by the late Professor J. J. Sederholm in connection with his life-long study of the Finnish migmatites. He applied this name to a group of migmatites which present an appearance that has suggested the terms " eruptive breccia " and " intrusion breccia ", but agmatite has a very different genesis from that connoted by these terms. Of agmatites

Sederholm (1923, p. 117) wrote: " As these migmatites consisting of fragments of older rocks cemented by granite are genetically and petrologically very different from many of the rocks that have been called eruptive breccias many of which are volcanic rocks, the author proposes to designate this group of migmatites as *agmatites* (from $\check{\alpha}\gamma\mu\alpha$, fragment)." The elaborate drawings and illustrations to be found in Sederholm's Memoirs (1923, 1926), however, give a much clearer idea of the appearance presented by these rocks than any written description.

In 1938, C. E. Wegmann (pp. 40–41) further emphasized the desirability of retaining agmatite as a purely descriptive term, writing: " It would be convenient, therefore, to give the term agmatite a merely descriptive meaning, that is to say, to let it denote merely a fragmental rock with a more or less granitic cement, saying nothing about its genesis. In so doing, we may reserve the genetically influenced conception 'intrusive breccia' for such cases in which the intrusion mechanics can be ascertained."

As long ago as 1925 Read (p. 33) pointed out the similarities between the migmatites and associated rocks of Rogart and those of Fennoskandia, which had already been made famous by the classical studies of Sederholm. In the former area a central granodiorite body is followed outward by a zone of migmatites which show, along the strike, every stage of transition to the various normal lithological types of the Moine country rocks. In the migmatite zone as a whole the main types of Moine rocks that formed the framework from which the migmatites were developed are siliceous granulites and semipelitic rocks; in addition there are subordinate pelitic schists, hornblendic rocks, and biotite-hornblende-schists, and smaller occurrences of more basic schists, e.g. hornblende-biotite-pyroxene-schists, that originated as dykes. Referring to the appearance of the fine grained biotite- and biotite-hornblende-schists in the migmatites, Read (1925, p. 27) stated: " these are intricately veined with thin strings of granitic material rather than soaked or lit-par-lit injected." In other words, they assume the form of agmatites. The writer has repeatedly noted this same phenomenon in the field and has found that it is characteristic both of the fine grained biotite-hornblende-schist and of the more basic schist of hornblende-biotite-pyroxene composition. Whereas the granulitic and semipelitic rocks commonly give rise to striped migmatites, the more compact basic varieties now appear as agmatites. This paper gives a brief account of the mode of occurrence of two types of agmatites and of the mineralogical and petrological changes that have taken place during their formation. The migmatization of the main Moine types and the origin of the granodiorite are to be described in another communication.

II. Agmatite Developed from a Fine Grained Biotite-Hornblende-Schist

1. *Field Observations*

Agmatite formed from the fine grained biotite-hornblende-schist is to be seen at its best on a polished, glaciated slab of rock outcropping south of Rogart Station. The outcrop is situated about 225 yards north-east of the Millnafua Bridge at the side of a road leading to Splockhill. Fortunately, the rock has been quarried at the roadside, and so can be studied in both plan and elevation (Text-fig. 1). In this slab dozens of fragments of biotite-hornblende-schist, and very rare fragments of siliceous granulite, ranging from 1 inch to 3 feet across, can be seen embedded in gneissose granodiorite. Many of the fragments are quite angular and distinctly exhibit the original features of the fine grained " pepper-and-salt " type of basic Moine schist. Others, as in the middle portion of the block, are very much changed both in their external form and in their internal structure and composition. By studying individual fragments, so spectacularly displayed in this exposure, it is possible to trace a complete sequence of change from practically unaltered relics of the biotite-hornblende-schist to ghost-like remnants dispersed through gneissose granodiorite which is itself a migmatite of the nebulite type.

Many of the angular fragments (indicated by close line shading on Text-fig. 1) are but slightly altered, except for a partial loss of schistosity due to a certain amount of recrystallization. This leads to the development of rocks that are more massive than any of their counterparts outside the area of migmatization. Every schist remnant, however, invariably exhibits a relatively basic rim (shown as a dark line on Text-fig. 1) against either the granodiorite or the obviously granitized schist as the case may be. These rims are characterized by aggregates of large biotite flakes and vary from 1 to 3 mm. in width.

With further alteration the colour of the schist fragments becomes gradually lighter than that of the normal rock (indicated by wider line shading and dots on Text-fig. 1), dependent on the progressive development within them of leucocratic lenticles and veinlets composed of sodic oligoclase and quartz. Even the least altered schist fragments are also sometimes traversed by small veinlets that cut across their foliation and show ptygmatic folding (P on Text-fig. 1). Feldspathic streaks and veinlets alike are practically always outlined on both sides by a thin film of relatively large biotite flakes, indicating that their emplacement involved a basification of the adjoining rock. Finally, the most altered fragments of schist no longer possess a definite outline, but fade imperceptibly into the surrounding gneissose granodiorite.

TEXT-FIG. 1

TEXT-FIG. 1.—A petrological sketch of a rock slab at the road-side, 225 yards N.N.E. of Millnafua Bridge, Rogart. The sketch shows an agmatite developed from a biotite-hornblende-schist. The upper portion is a map of the horizontal surface. The lower portions, *a'b'*, *b'c'*, *c'd'*, are the exposed elevations corresponding to the edges *ab*, *bc*, *cd* of the map. Line shading = biotite-hornblende-schist fragments bounded by biotite-rich rims, shown by heavy black lines, the thickness of which is slightly exaggerated for clarity of reproduction ; combined lines and dots = slightly granitized schist, with heavy dashed lines representing lines of biotite ; dots = dioritic migmatite ; white = granodiorite, with relict biotite and hornblende selvedges shown as heavy dashed and curved lines ; criss-cross lines = white granite. For a detailed description see pp. 3–5.

The granodiorite within which the schist fragments are embedded is characterized by strings of biotite (heavy dashed and curved lines on Text-fig. 1) with which hornblende is sometimes associated. Such basic streaks not only have every appearance of being relics of basic selvedges that originally outlined schist fragments, but they can sometimes be traced in continuity with such basic margins of schist. Such a continuity is seen at the western end of the exposure, and is indicated at X–Y in Text-fig. 1.

Whereas the fragments of biotite-hornblende-schist can be seen in every stage of conversion to gneissose granodiorite, conversely, the granodiorite, in its foliation and basic selvedge residuals, exhibits evidence of having developed by replacement of biotite-hornblende-schist. The agmatite as a whole has therefore been developed *in situ* as a result of the granitization of biotite-hornblende-schist. From the field evidence it is clear that step by step as biotite-hornblende-schist was granitized, the surplus basic materials were driven from the loci of granitization and fixed within the biotite-hornblende-schist. In the development of the initial arteries of granodiorite the surplus basic materials were driven into the residuals of schist, along the margins of which they developed basic rims. With the further advance of granitization, streaks and veinlets of granodiorite developed within the schist fragments, and in their turn became margined by basic selvedges. Finally, granodiorite characterized by biotite lenticles and streaks, residuals of basic margins, resulted.

Veins of biotite-poor granite cut through the agmatite. Since they generally cut across the greyish gneissose granodiorite with straight junctions it is clear that in this particular place their development post-dated the processes of migmatization. In some parts of the veins, however, the contact is not sharp, but shows gradation to the migmatite and granodiorite. An example of such a gradation was found at Z in Text-fig. 1. Moreover, where the margins of the veins are irregular the irregularities link up with the feldspathic streaks in the schist. Further, the margins of the veins are, in nearly all cases, bordered with a thin film of biotite. These features suggest that the veins may have been formed as a result of the continuation of the same processes that gave rise to the development of the feldspathic streaks and veinlets within the biotite-hornblende-schist.

2. *Petrology*

(*a*) *The biotite-hornblende-schist.*

The fine-grained biotite-hornblende-schist is a dark greyish black schistose rock consisting essentially of granoblastic plagioclase and quartz with small hornblende prisms and biotite flakes in subparallel arrangement. The plagioclase is a basic oligoclase An_{27} ; it forms

xenoblastic crystals, often slightly sericitized in the central portion. It is the most abundant constituent, and is followed in order of decreasing abundance by hornblende, biotite, and quartz. The biotite shows a pleochroic scheme of X = straw yellow < Y = Z = dark brown to black. The hornblende has 2V = ca 90°, Z $\wedge$ C = 23° and X = yellowish green < Y = green < Z = green with a bluish tinge. Quartz occurs as rare irregular grains. Accessories are sphene, apatite, zircon, chlorite, and ores, and the abundance of sphene is very noteworthy.

(*b*) *Biotite enrichment of the biotite-hornblende-schist.*

Where in juxtaposition with granitic material the schist exhibits a gradual loss of schistosity, becoming more lustrous and darker in colour. In thin section (1817) it is seen that the biotite has increased both in size and in quantity, whereas the hornblende has considerably decreased in amount. The abundance of large crystals of sphene and needles of apatite is also very noteworthy.

(*c*) *Migmatitic rocks derived from the biotite-hornblende-schist.*

With further changes the resulting rock shows abundant granitic areas along the " s " planes. The granitic lenses and strings are always rimmed with biotite flakes which serve to mark out the original structure. The most noteworthy feature, found in thin section (717*a*), is the increase in grain size and amount of the plagioclase and quartz. Quartz forms large irregular individuals, sometimes as much as 1·5 mm. across, which show slightly sutured contacts against the neighbouring plagioclase. The latter mineral, a basic oligoclase, occurs as subhedral crystals which are occasionally blebbed with rounded quartz. Biotite flakes and some relict hornblende have a subparallel arrangement as in the initial schist. The accessories, sphene and apatite, etc., have decreased in amount in comparison with the rocks described under (*a*) and (*b*).

(*d*) *The Gneissose Granodiorite.*

This rock, which represents the last stage of alteration of the schist, has a slightly foliated appearance marked by streaks of biotite and hornblende. In thin section (317) the granodiorite is found to be characterized by large porphyroblasts of orthoclase which developed chiefly at the expense of the plagioclase. The replacement resulted in a highly irregular sutured and saw-like junction between the two minerals, and some relict patches of sericitized oligoclase remain enclosed within the replacing orthoclase, still in optical continuity with the unreplaced portion outside. Clear rims of more acid oligoclase or even albite are found at the contact between the sericitized

oligoclase and the replacing orthoclase. The former mineral sometimes shows a marginal development of cauliflower-shaped myrmekite, the lobes of which project towards the orthoclase. Quartz shows sutured contacts against the oligoclase and occasionally includes this mineral. Biotite is sometimes chloritized. Other accessories are sphene, apatite, greën biotite, zircon, orthite, chlorite, and ores.

(*e*) *Geochemistry of the Transformations.*

In order to determine more exactly the mineralogical and chemical changes that took place during the migmatization of the biotite-hornblende-schist, micrometric measurements of the specimens described above were made and are recorded in Table I.

TABLE I.—MODES OF THE BIOTITE-HORNBLENDE-SCHIST AND ITS MIGMATITIC DERIVATIVES (VOLUME PERCENTAGES).

	A	B	C	D
Quartz	4·14	6·59	23·28	22·26
Plagioclase . . .	38·87	33·92	59·70	43·26
Orthoclase	—	—	·50	14·86
Myrmekite . . .	—	—	—	3·63
Biotite	20·74	38·23	13·01	13·59
Hornblende . . .	30·25	13·63	1·88	1·44
Sphene	5·48	5·42	·49	—
Apatite, chlorite, ore, etc. .	·53	2·18	·99	1·01
	100·01	99·97	99·85	100·05

A. Biotite-hornblende-schist, No. 1717.
B. Biotite-enriched biotite-hornblende-schist, No. 1817.
C. Migmatite of dioritic composition, average of Nos. 717 *a* and *b*.
D. Granodiorite, average of Nos. 317 and 1117.

The most noticeable mineralogical change from A to B is biotite enrichment ; such a change implies an increase in the K_2O and in the total of iron oxides and MgO. It also implies a decrease of CaO.

In the initial stage of migmatization illustrated by the passage from B to C there is an increase in the amount of plagioclase and quartz, and a concomitant decline in the amount of hornblende and biotite. At this stage of migmatization the chemical changes must have involved at least an increase of SiO_2 and Na_2O, with a concomitant decrease in at least K_2O, FeO, MgO, TiO_2, and P_2O_5.

The material lost in the initial stage of migmatization would adequately account for the development of the biotite-rich rims along the margins of the newly-developed leucocratic lenses and veinlets. It is also clear that the introduction of similar materials into the initial biotite-hornblende-schist would account for the biotitization that gave rise to the basic rims around schist fragments. Granitization and biotitization thus appear as complementary processes ; as one portion of the biotite-hornblende-schist was granitized, K_2O and total

FeO + MgO decreased and the adjacent part of the schist became enriched in these materials.

In the final change from C to D the fact that oligoclase was replaced by orthoclase, whilst the percentage of biotite remained essentially unaltered, implies that there was an influx of K and a loss of Na. Here again a complementary relationship is apparent, for the formation of the granodiorite involved the liberation of Na necessary for the development of more dioritic rock like that of the preceding stage of change. It should perhaps be emphasized by way of explanation that the complementary changes that are here described as a sequence in time, must, as granitization progressed, have also proceeded as a progressive sequence in space, so that materials liberated at one locus would become available at another.

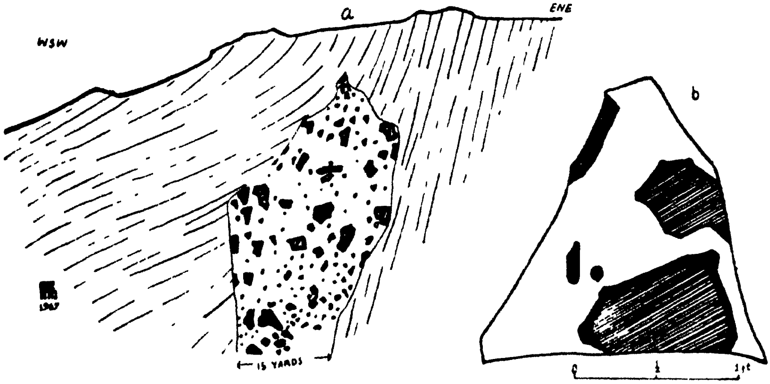
III. Agmatite Developed from a Basic Schist of Igneous Origin

1. *Field Observations*

Another group of agmatites is found in basic schist bodies that represent a series of older basic igneous dykes. These were intruded prior to the period of Moine metamorphism during which they, together with the country rocks, were rendered schistose. The basic schist bodies are all more or less elongated in shape, and none of them attain great size. They usually truncate the bedding of the Moine rocks, thus indicating that they were of intrusive emplacement. During the first stage of migmatization, these bodies are commonly intricately veined with thin strings of granitic material that is more resistant than the schist and stands out after weathering as small ridges, thus giving the rock a honeycombed appearance. The further stage of migmatization is characterized by the widening of the granitic portions and the dissection of the schist into isolated angular fragments.

The example of agmatite here presented (Text-fig. 2*a* and Pl. I, fig. 2) is taken from the largest of these bodies, which is situated on the eastern side of Creag a' Bhata at the small rock cliff above the hill-path from Pittentrail to Little Rogart. The body is roughly lenticular in plan, the widest part measuring about 20 yards and the length about 50 yards. It has a vertical dip crossing the bedding of the Moine granulites. Granulites and dyke alike have been granitized. The granitization follows the bedding in the granulites giving rise to striped migmatites. Within the framework (Text-fig. 2*a*) of the original dyke-shaped schist body, however, the rock has been divided into numerous fragments separated by granodiorite, and is thus now a typical agmatite. The preservation of the original solid framework, with retention of the dyke-shaped form of the schist-body, and lack of disturbance of the bedding of the granulites makes it obvious that

the granodiorite was not emplaced as magma. If such had been the case room for its emplacement could only have been provided by either (1) expansion, or (2) downward stoping. It is clear, however, that neither of these mechanisms has been operative, for the original solid framework of the dyke and enclosing granulites is neither distorted nor disturbed, as would be the case if expansion had taken



TEXT-FIG. 2.—(a) A sloping section showing the shape of a basic schist body now represented by agmatite, and its relation to the surrounding migmatized granulites. The fragments inside the body are represented to some extent schematically. Creag a' Bhata, North of Pittentrail, Rogart.

(*b*) A larger scale drawing of part of the rock surface of the agmatite showing basic schist fragments (line shading) with basic rims (solid black), and also residual basic clots in the diorite-granodiorite (white).

place ; and the rocks cannot have sunk for the pre-migmatization geology is still preserved.

Within the agmatite the schist fragments have been altered both chemically and mineralogically, with the production of a great variety of mixed rocks, and although in many of these the characters of the original schist have been in large measure obliterated, we nevertheless commonly find the schistosity preserved, although with progressive alteration it becomes less and less conspicuous. Nearly all the fragments were basified during the first stage of migmatization, as a result of which they now contain pyroxene, biotite, and hornblende. Moreover, every schist fragment is bounded by a basic rim, usually composed of hornblende. Outside the basic rim there is a gradual passage from pyroxene-diorite through quartz-diorite to granodiorite. Within the granodiorite every transition can be found from schist fragments with basic rims to clots, composed mainly of hornblende, which represent the completely basified relics of residual schist.

2. *Petrology*

The petrography of the various rocks composing the agmatite is here presented in the order of the field sequence, passing outwards from the centre of a schist fragment (see Text-fig. 2*b*), under the following headings :—

(*a*) Hornblende-biotite-pyroxene-schist (basified schist).
(*b*) Hornblendic rims and clots.
(*c*) Pyroxene-diorite, quartz-diorite and granodiorite.

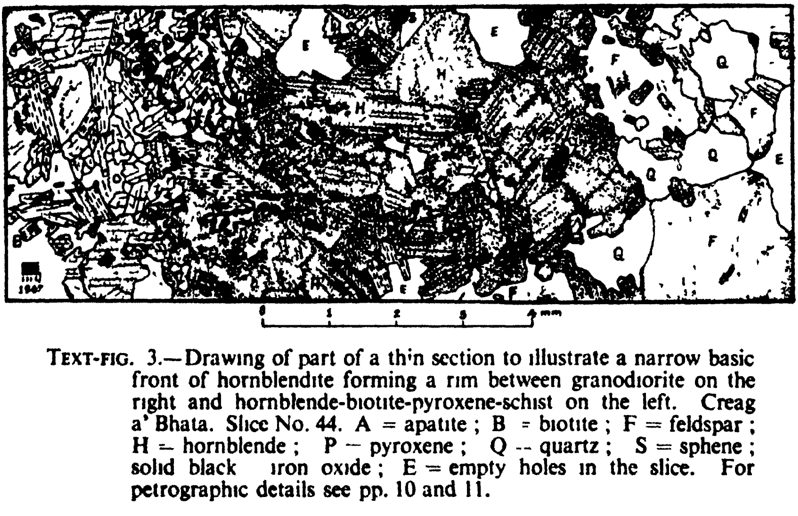
(*a*) *Hornblende-biotite-pyroxene-schist (basified schist).*

The altered schist forming the fragments is a medium-grained greenish black rock consisting of large aligned plates of biotite and prisms of hornblende embedded in a greenish base of pyroxene and feldspar. In thin section (10) it is seen to consist dominantly of clino-pyroxene, biotite, hornblende, and patches of feldspar. Apatite and sphene are abundant accessories with subordinate orthite, tremolite, and black ores. The clino-pyroxene is a nearly colourless diopsidic augite ($Z \wedge c = 39° – 40°$), with occasionally a slight greenish tinge ; it occurs as short euhedral or subhedral prisms and is often included in the large crystals of hornblende and biotite. Hornblende with X = light green to colourless < Y = green with a yellowish tinge < Z = green, forms prisms or large patchy crystals up to 5 mm. in length, which are often sieved with feldspar, abundant rounded grains of pyroxene and flecks of biotite. Biotite is pleochroic from pale yellow to brown, and appears both as large plates and as small irregular replacements within the pyroxene. Oligoclase, to some extent sericitized, is the dominant feldspar, but orthoclase is also present in subordinate amount, as large crystals which enclose the other components. Large brownish subhedral crystals of slightly pleochroic sphene, and large stout prisms of apatite up to 2 mm. in length are very abundant ; the apatite usually contains dusty inclusions.

(*b*) *Hornblendic Rims and Clots.*

The narrow rims bounding the schist fragments range from a few mm. up to about half an inch or more in width, and the basic clots in the granodiorite, relics of schist that has been completely basified, may reach a size of 2 or 3 inches across. The latter are irregular in shape. Both rims and clots are built chiefly of large hornblende prisms, 2 by 3 mm. in size, interrupted by sporadic patches of pinkish feldspar. In thin section (44 and 49, see Text-fig. 3) they are found to consist dominantly of large prisms of hornblende with interstitial areas of plagioclase. The accessories, apatite and sphene, are noteworthy both

for their relatively large size and for their abundance ; they may form as much as 10 per cent of the rock. Other accessories are biotite, pyroxene, and ores. The hornblende has X = pale green < Y = green with a yellowish tinge < Z = green, and is usually characterized by an abundance of inclusions of greenish yellow biotite flecks, pyroxene grains, and small apatite rods. The plagioclase is a sodic oligoclase and is sometimes partly replaced by orthoclase around its margins. The hornblendite of the basic rims and the associated types to which it grades resemble the appinite suite.



TEXT-FIG. 3.—Drawing of part of a thin section to illustrate a narrow basic front of hornblendite forming a rim between granodiorite on the right and hornblende-biotite-pyroxene-schist on the left. Creag a' Bhata. Slice No. 44. A = apatite ; B = biotite ; F = feldspar ; H = hornblende ; P = pyroxene ; Q = quartz ; S = sphene ; solid black iron oxide ; E = empty holes in the slice. For petrographic details see pp. 10 and 11.

(*c*) *Pyroxene-diorite, quartz-diorite, and granodiorite.*

The rock outside the hornblendite rims of the schist fragments is very patchy, and includes a series of rock types leading up to granodiorite. The rock immediately outside the rim is a greenish grey, medium-grained, pyroxene-rich rock containing black prisms of hornblende. It is seen in thin section (9) to be a pyroxene-diorite containing stout prisms of pale greenish diopsidic augite with a rough alignment ; their gradual change over to hornblende is in many places well displayed. Large crystals of hornblende, often twinned, are present and measure up to 5 mm. across. They have X = yellowish green < Y = green < Z = green with a bluish tinge. Small rounded inclusions of pyroxene, olive-brown biotite, and apatite occur within the hornblende. Oligoclase, An$_{27}$, forms irregular crystals ; it is usually sericitized and marginally replaced by orthoclase. Quartz also forms irregular individuals. Apatite and sphene are still comparatively abundant, and it is noteworthy that some of the apatite

prisms contain inclusions of pyroxene. Other accessories are green biotite, rutile, and opaque ores.

Further away from the margins of the schist fragments the rock becomes more and more granitic looking, and occasionally contains light greenish pyroxene-rich patches that represent relict ghosts of the basified schist. In thin section (8) a fair amount of clino-pyroxene (5·9 per cent in this particular slice) can still be seen in the rock, but most of it shows various stages of transformation to hornblende. Biotite occurs only as small inclusions within the hornblende. The amount of quartz has increased considerably in comparison with the rocks previously described, and orthoclase is present in small amount.

The final stage of granitization is represented by a more homogeneous granitic-looking rock with hornblende as the only mafic mineral. In thin section, however, it is found to vary from quartz-diorite to granodiorite in composition. The quartz-diorite (7) is composed almost entirely of large individuals of plagioclase and quartz. The former, oligoclase An_{26}, occurs as subhedral crystals which commonly show a combination of fine albite and carlsbad twinning. The quartz exhibits sutured margins towards the plagioclase. In the granodiorite (44*a* and *b*) orthoclase is a conspicuous constituent, forming a quarter of the total feldspar. It has clearly formed by replacement of the oligoclase, of which it often contains optically continuous relics. Moreover, orthoclase can commonly be seen to enclose isolated, though optically continuous, portions of an adjoining crystal of oligoclase. Myrmekite is widespread as cauliflower-shaped protuberances from the plagioclase where it adjoins orthoclase. The oligoclase has a clear margin of more sodic composition where it adjoins the replacing orthoclase. Quartz is very irregular in shape and exhibits sutured margins, typical of replacement, where it adjoins the feldspars. The accessories in both the diorite and the granodiorite are sphene, apatite, biotite, green biotite, and black ores.

(*d*) *Geochemistry of the transformations.*

The results of the micrometric analyses of the various rocks composing the agmatite are set out in Table II. The development of the hornblendic rim F from the basic schist E is one of basification. This is indicated not only by an increase in the sum of the mafic minerals together with a slight increase in the amounts of apatite and sphene, but also by the complementary decrease in the amounts of oligoclase and orthoclase. Chemically the change implies an increase in one or more of the cafemic constituents, and in TiO_2 and P_2O_5, whilst the marked decrease in biotite and orthoclase from E to F indicates a complementary decrease in K_2O. These changes are even more strongly marked in the basic clot, G, that represents a more advanced

stage of both basification and desilication of the hornblende-biotite-pyroxene-schist. From a comparative study of a large number of chemical analyses of rocks representing the basic fronts of granitization, D. L. Reynolds (1946) has shown that such basic fronts are particularly characterized by an increase in one or more of the minor constituents TiO_2, P_2O_5, and MnO. By comparing the modes of E, F, and G in Table II, it can be seen that TiO_2 and P_2O_5 have been concentrated differentially within the basic front itself; P_2O_5 first reached its culmination in the basic rims, and TiO_2 subsequently attained its culmination in the basic clots.

TABLE II.—MODES OF THE VARIOUS ROCKS COMPOSING THE AGMATITE DEVELOPED FROM A SCHISTOSE BASIC DYKE (VOLUME PERCENTAGES).

	E	F	G	H	I	J
Quartz . . .	—	·76	—	6·31	34·37	32·07
Oligoclase . . .	9·92	6·59	3·28	40·87	49·83	42·80
Orthoclase . .	3·18	2·02	1·49	1·87	1·02	14·66
Myrmekite . .	—	—	—	—	·68	·87
Hornblende . .	17·16	79·17	85·33	10·81	12·77	8·77
Biotite . . .	25·85	2·62	6·39	—	·32	—
Clinopyroxene . .	36·82	1·88	1·13	36·25	—	—
Sphene . . .	·57	·71	1·07	·81	·56	·68
Apatite . . .	4·58	4·74	·63	3·04	—	·13
Chlorite, ores, etc. .	1·86	1·47	·67	·02	·43	·01
	99·94	99·96	99·99	99·98	99·98	99·99

E. Hornblende-biotite-pyroxene-schist (basified schist), No. 10.
F. Hornblendite rim, No. 44, from the margin of a schist fragment.
G. Basic clot, No. 49, in the granodiorite.
H. Pyroxene-diorite, No. 9, immediately outside a basic rim.
I. Quartz-diorite, No. 7.
J. Granodiorite, average of Nos. 44 *a* and *b*.

The migmatization of the basified schist is seen in the series pyroxene-diorite (H) → quartz-diorite (I) → granodiorite (J). Throughout this rock series the change is essentially one of feldspathization. In the initial stages of migmatization, as exemplified by H and I, oligoclase and quartz show marked increase in amount, the total cafemic minerals decrease, biotite practically disappearing, and pyroxene is gradually replaced by hornblende. As judged from the mineralogy, the chemical changes must have involved the introduction of Na and Si, and the driving out of K, Fe, Mg, and the minor constituents Ti and P.

With the development of granodiorite, representing the final stage of migmatization, orthoclase increased in amount, and there is a complementary decrease in oligoclase together with a further decrease in the cafemic minerals, now represented solely by hornblende, and in apatite and sphene. This stage of granitization involved at least the

introduction and fixation of K, which may in part be accounted for by the K liberated in the formation of the basic fronts.

The materials displaced from the basic schist during the migmatization included at least Fe, Mg, Ti, and P, a large part, perhaps all, of which are now represented in the hornblendite clots and rims that represent the basic fronts of the migmatization.

IV. Discussion and Conclusions

From the preceding field and petrological observations it is evident that the two varieties of agmatites described from the Rogart area were formed *in situ* from solid rock as a result of recrystallization dependent on introduction, diffusion, fixation, and expulsion of migrating chemical elements, probably in an ionic state. The agmatites cannot have arisen as a result of intrusion or eruption for such processes would inevitably have caused disruption and displacement of the solid framework of the pre-existing rocks.

The critical field evidences are :—

(*a*) The fragments of the agmatites still retain their original orientation in the unobliterated framework.

(*b*) Considerations arising out of the space problem. If the granitic-looking rocks had resulted from the intrusion of magma there would have been either an increase in volume or a corresponding removal of the country rocks. It is clear in the field that neither phenomenon has taken place.

(*c*) The fragmentary inclusions of the agmatites constitute an evolutionary sequence from indisputable original types, through basified rocks to more or less granitic-looking migmatite with ghost-like relics and basic clots.

The critical mineralogical and textural evidences are :—

(*a*) The replacement habit of many minerals, as exemplified by the relation of potash feldspar to plagioclase and biotite, and of hornblende to clino-pyroxene.

(*b*) The sutured outlines of quartz where it adjoins plagioclase.

(*c*) The development of myrmekite.

(*d*) The poikiloblastic or skeletal character of some of the minerals, e.g. biotite and hornblende.

The fact that the agmatites in the Rogart migmatite area are developed either from the fine-grained biotite-hornblende-schists, or from hornblende-biotite-pyroxene-schists of igneous origin is probably to be related to the more compact nature of these rock types as compared with the main Moine rocks. In consequence the transformation, instead of following well-spaced " s " planes, as in the other members of the Moines, takes place along more irregular routes.

The sequence in the development of the rock types in the evolution

of the agmatite is completely in accord with the important conclusions drawn by D. L. Reynolds (1946, p. 390) in her recent study of the chemistry of rocks associated with granite, namely : " just as skarn develops in limestones at granite contacts as a result of the introduction and fixation of iron, magnesium, alkalis, etc., so the initial change in rocks of all types includes enrichment in mafic constituents and alkalis. Only subsequently are the rocks granitized in the strict sense of the term." Moreover the products of the initial desilication change " may attain the composition of syenite or of basic or ultrabasic igneous rocks ", and " when the desilication change is wholly or largely one of basification (introduction of Fe, Mg, Ca) it is characterized by increase, commonly attaining geochemical culmination, of one or more of the minor constituents TiO_2, P_2O_5, and MnO ".

In the first example of agmatite here described the migmatite evolved through quartz-diorite to granodiorite, and in the second example through pyroxene-diorite and quartz-diorite to granodiorite. In both cases the sequence of evolution was thus from more sodic to more potassic varieties. A similar association and sequence in the development of sodic and potassic rocks was found by Y. C. Cheng (1942) in the migmatites of North Sutherland, and by D. L. Reynolds (1943) in the granitized rocks of Goraghwood quarry, Northern Ireland.

The development of the migmatitic, i.e. the granitic portions of the agmatites, was accompanied by the introduction of cafemic constituents and alkalies into the residual schist fragments with the consequent development of basic rims, selvedges, and clots. In the first example such rims and selvedges are characterized by richness in biotite, implying the introduction of at least Fe, Mg, and K. In the second example the zones of hornblende enrichment imply the fixation of at least Fe, Mg, Ca, and Na. This local concentration and fixation of basic elements is a small scale example of the Fe-Mg " front " (Wegmann, 1935 ; Backlund, 1936, 1943 ; Reynolds, 1942, 1943, 1944), the importance of which has recently been emphasized by D. L. Reynolds (1947). The mechanism of aggregation and fixation of such diffusing materials has also recently been discussed by Holmes and Reynolds (1947).

It is worthy of notice that in the present study the basic front has been found to be more strongly developed in the second example owing to the more basic composition of the initial hornblende-biotite-pyroxene-schist from and within which it was formed. In consequence a greater supply of basic materials was displaced during granitization with the result that the hornblendic basic fronts eventually reached an ultrabasic composition.

Having established the sequence of formation of the various rock types within the two varieties of agmatite, and the mineralogical and

chemical changes that took place during their development, it remains to consider the origin of the rocks which constituted the solid framework from which the agmatites were formed. In the first example transitions from the biotite-hornblende-schist to the neighbouring Moine rocks of sedimentary origin suggest that it likewise had a sedimentary origin. Mineralogically it resembles the biotite-hornblende-plagioclase-diabrochite, developed from diopside-hornfels of Silurian age in the Newry area, Northern Ireland (Reynolds, 1944, pp. 220–1), and this resemblance suggests that it may represent a chemically reconstituted calcareous shale or marl.

The hornblende-biotite-pyroxene-schist of the second example closely resembles the pyroxene-biotite-hornblende-schist described by Y. C. Cheng (1942) from the Bettyhill area in the north of Sutherland. It also resembles the widespread " Ach'uaine hybrids " described by Read (1925, pp. 45–50; 1926, pp. 154–166; 1931, pp. 165–172) from Sutherland. For these reasons the real nature of this rock and its relations to the various alteration products described in this paper are, I think, of sufficient interest to merit more detailed discussion.

As already shown in the earlier part of this paper the hornblende-biotite-pyroxene-schist represents a basic dyke that was emplaced before the period of Moine metamorphism that gave rise to the schistosity of the Moine rocks. The curious mineral composition of the hornblende-biotite-pyroxene-schist, however, in which sodic oligoclase and orthoclase are associated with a high percentage of mafic minerals makes it difficult to believe that it is an unaltered basic igneous rock. Cheng (1942, pp. 72–3) considered that the pyroxene-biotite-hornblende-schist of the Bettyhill area, together with the associated members of the hornblendic complex, represent hybrids that were produced by the " mixing of a granitic magma with an ultrabasic magma or with solid ultrabasic rocks " prior to the period of general migmatization in a way similar to that which had previously been suggested by Read (1926, pp. 154–166) for the " Ach'uaine hybrids ". Finding himself unable to distinguish the acid member of the supposed hybrids from the supposedly younger migmatites, Cheng suggested that the acid members responsible for the hybridization lost their identity when the rocks became subsequently migmatized. He further considered that the acid magma responsible for the hybridization was possibly the vanguard of the granites of the regional " injection-migmatization ". In making these suggestions Cheng attempted to separate what can now be seen to be one continuous process into two similar and indistinguishable stages.

The evidence furnished by the occurrence of hornblende-biotite-pyroxene-schist described in this paper is insufficient to establish the

origin of the rock, but the writer will in a later communication present detailed evidence from other localities in the Rogart area to show that the hornblende-biotite-pyroxene-schist is itself a derivative from a member of the epidiorite–amphibolite suite. The hornblende-biotite-pyroxene-schist actually represents the initial stage of basification of a member of this suite, such a basification being complementary to the general migmatization of the surrounding rocks. The further evolution from hornblende-biotite-pyroxene-schist to hornblendite, dioritic rocks (members of the appinite suite) and migmatites has been described above. This evolution is to be attributed to one continuous process of solid diffusion (without the introduction of granite magma) in the course of which the development of migmatites involved the liberation of mafic constituents which were fixed in the basic rocks, thereby converting them to hornblendites.

The complete sequence of recognizable changes through which the basic rocks have passed is probably (1) basic schist → (2) hornblende-biotite-pyroxene-schist → (3) hornblendite → (4) appinitic rocks → (5) migmatite → (6) granodiorite. The study of these changes yields, in my opinion, an important clue towards the elucidation of the puzzling " Ach'uaine hybrids ".

ACKNOWLEDGMENTS

The writer wishes to express his indebtedness to Dr. Doris L. Reynolds and Professor Arthur Holmes for their illuminating advice, encouragement, and constructive criticism given to him during this work, and his gratitude to the British Council for the award of a scholarship that enabled him to study in Britain.

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DESCRIPTION OF PLATE

FIG. 1.—A relict fragment of slightly granitized biotite-hornblende-schist in granodiorite at the road-side of Milton bank, north of Rogart Station. Note the basic rim developed from the schist at its margin against the granodiorite.

FIG. 2.—Agmatite developed from basic schist Part of the rock surface illustrated in Text-fig. 2. Creag a' Bhata, north of Pittentrail, Rogart.

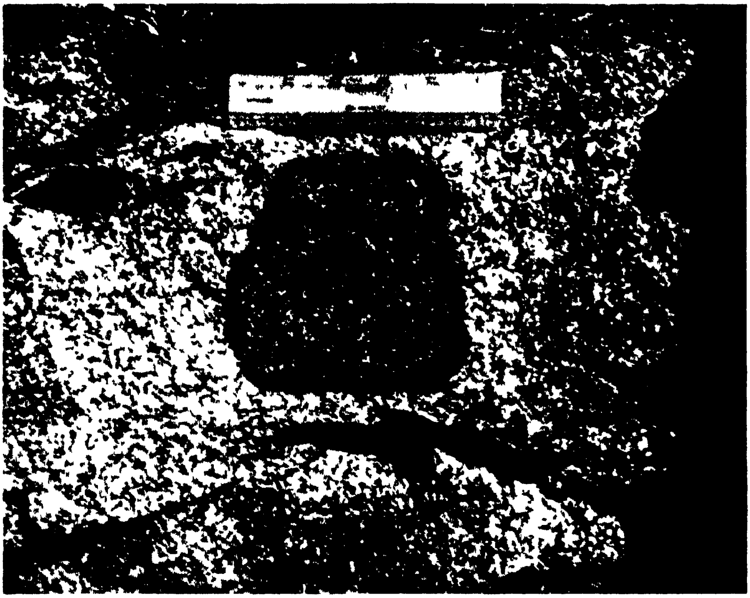


FIG. 1

FIG. 2

AGMATITE FROM THE ROGART AREA, SUTHERLANDSHIRE.

Rhynchonellids of the Boueti Bed of the Great Oolite Series of Langton Herring, Dorset : A Study in Variation

By W. G. AITKEN and W. S. MCKERROW

(PLATES II AND III)

I. INTRODUCTION

THIS paper gives the results of a statistical study of the variation in a community of rhynchonellids from the Boueti Bed of the Great Oolite Series. The material was obtained during a visit to Dorset on the Students' Summer Tour organized by the Geological Society of London (1946) under the directorship of Mr. G. M. Davies and Dr. Alan Wood. The specimens constitute a random collection from the locality one mile south of Langton Herring (Map Ref. Nat. Grid 30'612811) where the outcrop of the Boueti Bed crosses the shore of the Herbury backwater of the Fleet and where wave action has removed the shells from the clay matrix in which they have been preserved. In the majority of cases the shells are in an admirable state of preservation, although they are frequently encrusted with fossil Polyzoa.

Advice and encouragement from Professor D. Leitch in the course of this study are gratefully acknowledged. Thanks are also due to Dr. A. E. Trueman, Professor T. Neville George, Dr. J. Weir, and Dr. R. A. Robb for helpful suggestions and criticism ; and to Dr. Helen M. Muir-Wood, of the British Museum (Natural History), for examining and commenting upon a number of specimens from the collection.

II. SYSTEMATICS AND NOMENCLATURE OF THE LANGTON HERRING GONIORHYNCH RHYNCHONELLIDS

The species *Rhynchonella boueti* was first described by Davidson (1852) from Ranville, Caen, Normandy.

Subsequent illustrations by Davidson (1878) of *R. boueti* from Langton Herring and Burton Bradstock differ markedly from the type especially in the nature of the ribbing and in the relative dimensions. These differences were later referred to by Buckman (1917), who assigned *R. boueti* Davidson to a new genus, *Goniorhynchia* (genotype *G. goniaea* Buckman), claiming that Davidson's original species in fact included several species. Of these he named two, *G. goniaea* (from the "Forest Marble Rhynchonella Bed", Eype, Bridport, Dorset) and *G. contracta* (from the same horizon, Burton Bradstock, Dorset). (See Plate II.)

In the present collection, shells which on external characters appear to be identical with *G. boueti* (Davidson) s.s. 1878 or *G. goniaea* Buckman 1917 or *G. contracta* Buckman 1917 are infrequent, although in many of the variants the form of such individual biocharacters as the profile of the sulcus or the outline of the shell may be typical of these species.

Dr. Helen Muir-Wood has kindly compared a number of specimens in our collection with the large collection from this locality in the British Museum (Natural History). She suggests that there may indeed be several species and perhaps more than one genus of rhynchonellids in the Langton Herring community, although she notes that the shells exhibit a wide range of variation.

The present study is based entirely on external characters and on only a few measurable features ; it leads to the conclusion that in these characters at least, the variation is continuous, and that the community appears to be homogeneous. We recognize that internal characters may in due course provide grounds for morphological distinction and for nomenclatural subdivision ; but in the light of available evidence, we regard such subdivision as at present arbitrary.

III. Description of the Variation

Considerable proportionate variation occurs in the length, breadth, and thickness of the shells, and in the nature of the sulcus and the ribbing. Three main series displaying variation in shell shape may conveniently be recognized. These are illustrated in Plate II (in which the directions and alignment of the series are of course conventional and are not defined with mathematical precision). The variation gives rise to several extremes, which can, however, be continuously graded to a norm from which the variation series may be regarded as radiating.

(1) The end members of series 1 have the position of maximum breadth close to the anterior border, and are thus of roughly triangular outline. The more triangular shells are often proportionately thicker than the norm.

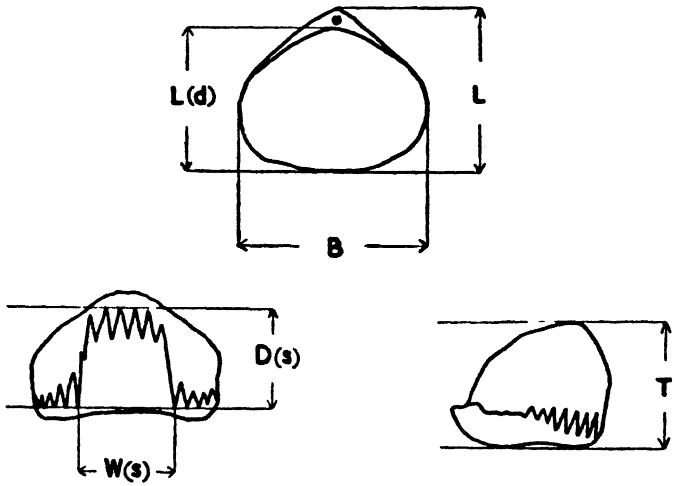
(2) The extremes of series 2 have a rhomboidal outline since the position of maximum breadth is central. They are generally relatively thinner and broader than the norm.

(3) The members of series 3 exhibit roundness both in outline and convexity of the valves, especially of the dorsal valve. In the extreme forms this is accompanied by the elimination of the trilobate character of the shells and by a decrease in the depth of the sulcus.

Some variation also occurs in the nature of the ribbing and of the sulcus, but it is not practicable to represent this in Plate II, partly because there is no close correlation between the form of ribs and

sulci and the shell outline. Variation in the ribbing has not been treated statistically ; but as far as could be gauged by eye, there was no evidence of discontinuity.

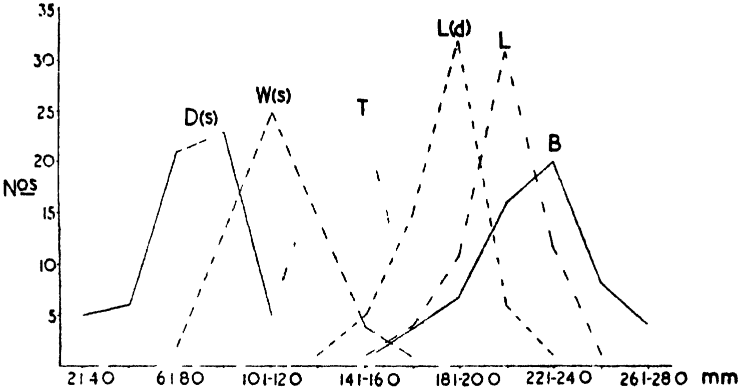
The top left inset to Plate II is a distribution scatter of the whole group of variants superimposed on a framework of the main variant types. The black circles represent the figured specimens, the other circles indicating the general relationship in external shell shape of the unfigured intergrades. It will be noted that, although in Plate II, " A " is chosen as the norm from which variation may be said to



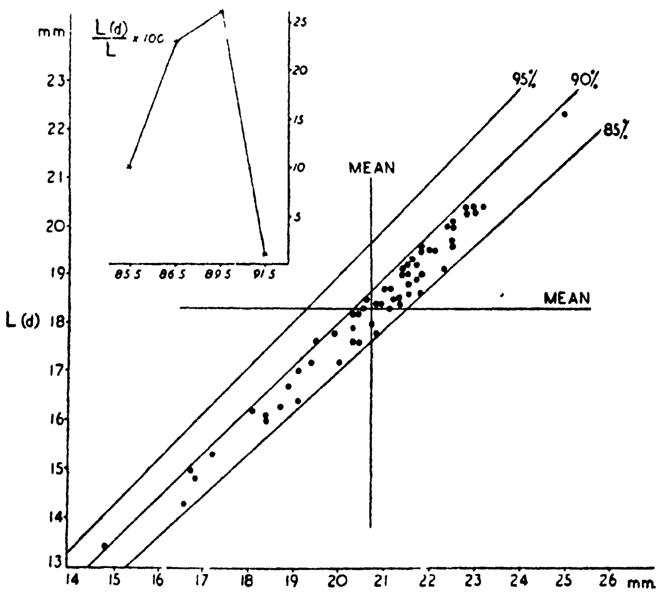
TEXT-FIG. 1.—The directions of measurement used in the statistical study.

radiate, it is not the most frequently occurring type, the majority of the shells being equally divided between series 1 and series 2, with intergrades, less rounded in outline than the central type, linking these two series. It will be shown that a scatter based on measurements of three variables gives similar results.

Plate III illustrates the variation in the form of the sulcus. The variation is not only continuous, but it also shows some correlation with the lines of variation in the general scatter (Plate II). Thus the shells of series 1 usually possess a sulcus the sides of which are almost parallel ; in series 2 the divergence of the margins of the sulcus is most marked ; in series 3 the sulcus is almost non-existent. This correlation of the nature of the sulcus with the main lines of variation is only partial, particularly in the case of series 2 where an increasingly rhomboidal outline is not necessarily accompanied by a corresponding increase in the divergence of the sulcus margins.



TEXT-FIG. 2.—Frequency polygons of the values of the six variables measured.



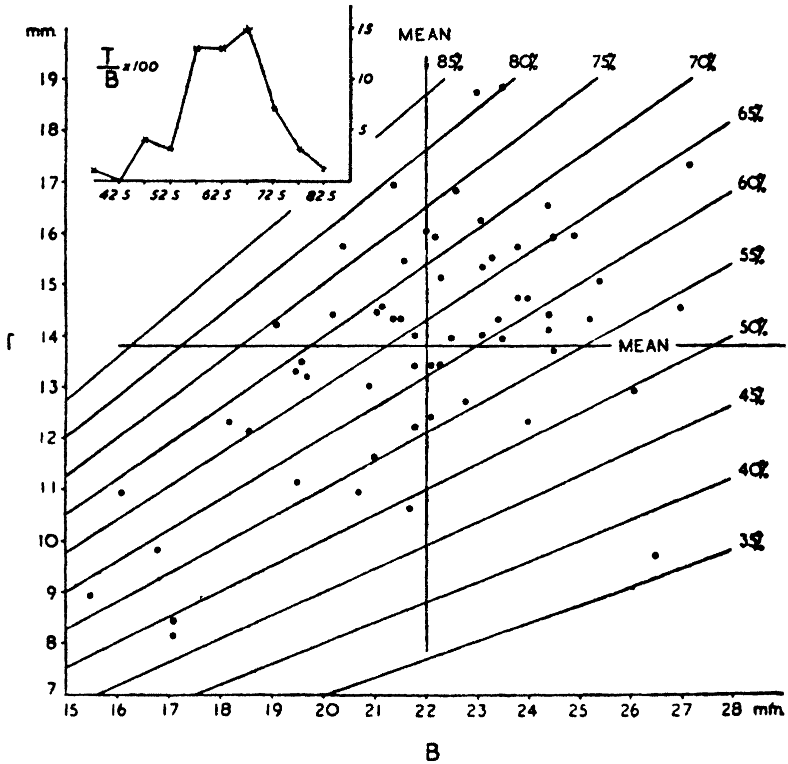
TEXT-FIG. 3.—The relation between the lengths of the dorsal [L(d)] and the ventral [L] valves.

Inset: Frequency polygon of the ratios of these variables.

IV. Statistics of Variation

Sixty specimens were examined statistically. The directions of measurement are indicated in Text-fig. 1 ; these are :—

(1) From the anterior commissure to the most distant point in the ventral valve [L] ;



Text-fig. 4.—The relation between the thickness (T) and the breadth (B) of the shells.

Inset : Frequency polygon of the ratios of these variables. Class marks of alternate intervals only are numbered.

(2) From the anterior commissure to the most distant point in the dorsal valve [L(d)] ;

(3) Breadth [B] ;

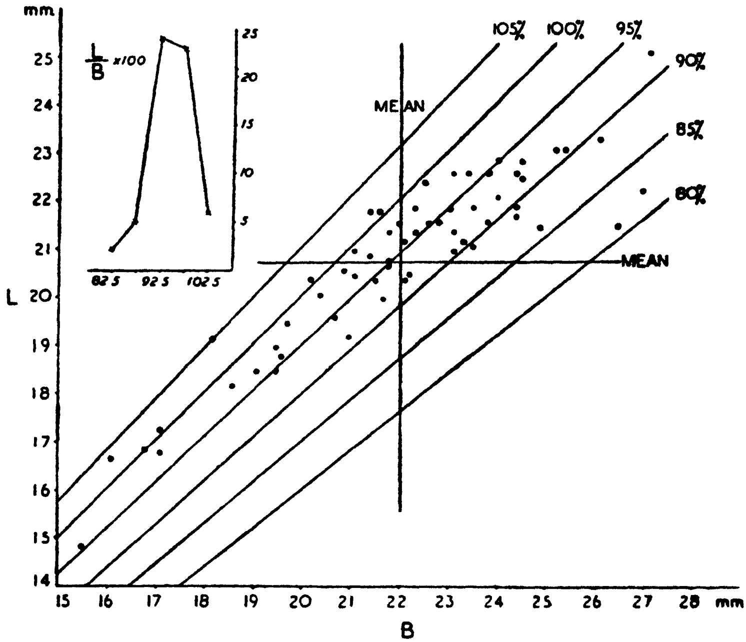
(4) Thickness with ventral valve resting on a flat surface [T] ;

(5) Depth of the sulcus [D(s)] ;

(6) Width of the sulcus [W(s)].

Frequency polygons of the values of each of the six variables have been constructed (Text-fig. 2); each of these shows a single maximum (mode). A greater concentration of values is apparent round the modes of L and L(d) than is seen for the other variables.

Frequency polygons for selected ratios of the six variables have



TEXT-FIG. 5.—The relation between the length (L) and the breadth (B) of the shells.

Inset: Frequency polygon of the ratios of these variables. Class marks of alternate intervals only are numbered.

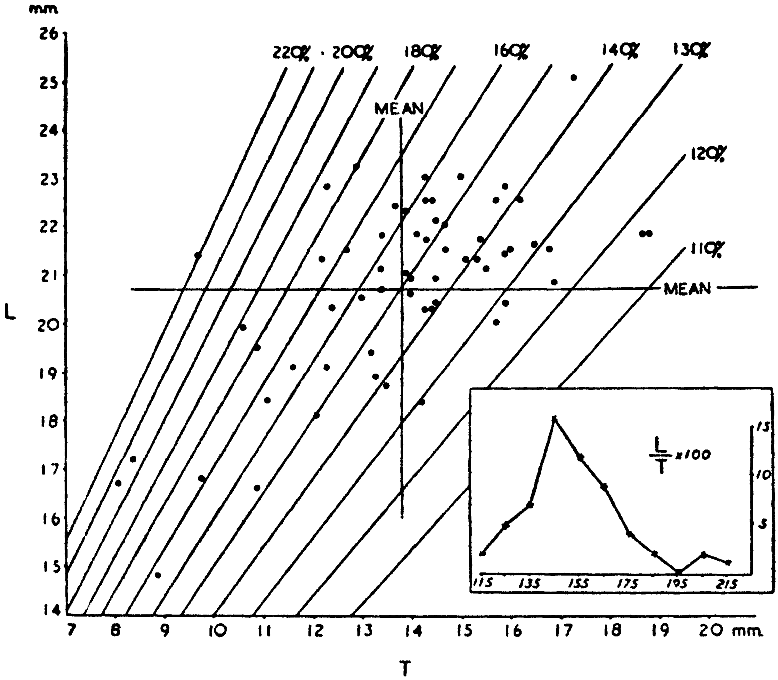
also been constructed (see insets to Text-figs. 3–9). Statistical details concerning these ratios are given in Table I. A mathematical measure of the distribution of values of each of the ratios is given by the standard error.

TABLE I

Ratio.	*Mean.*	*Standard Error.*
L(d)/L	0·881	0·015
T/B	0·627	0·085
L/B	0·944	0·045
L/T	1·526	0·203
D(s)/W(s)	0·667	0·172
W(s)/B	0·519	0·064
D(s)/T	0·540	0·102

In Text-figs. 3–9 scatter-diagrams have been obtained by plotting combinations of the variables. The mean value of each variable is plotted. To enable the value of each variable to be read as a percentage of the other, equal-ratio lines have been drawn. These correspond to the divisions between the class intervals used in the frequency polygons of the ratios (see insets).

The correlation existing between pairs of variables differs considerably. The length of the dorsal valve is so closely correlated with



TEXT-FIG. 6.—The relation between length (L) and thickness (T) of the shells. Inset : Frequency polygon of the ratios of these variables. Class marks of alternate intervals only are numbered.

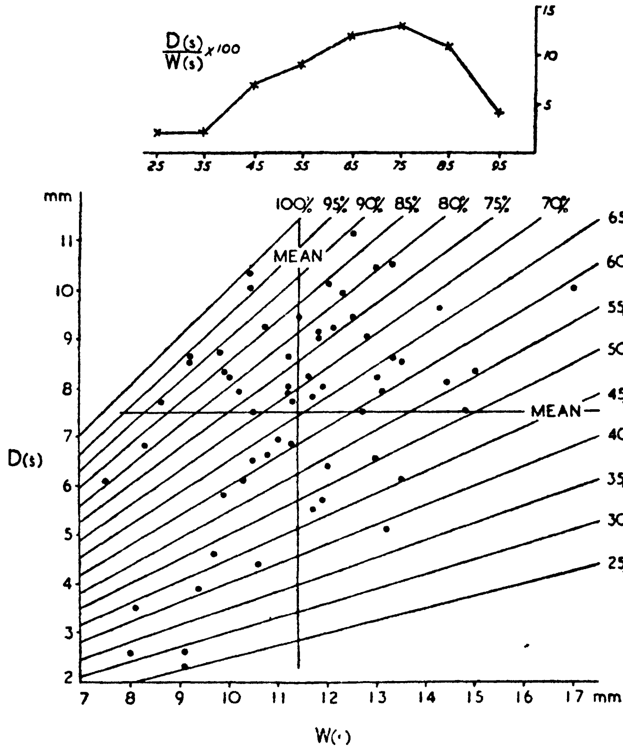
that of the ventral valve, L (d) invariably lying wholly between 85 per cent and 91 per cent of L (Text-fig. 3), that it is considered unnecessary to discuss separately the relation of L(d) to the other variables. On the other hand, the thickness and breadth of the shells are less closely correlated. This is reflected in the extent of the scatter in Text-fig. 4.

V. THE THREE-VARIABLE SCATTER-DIAGRAM

The main disadvantage of the methods of statistical study of which use has been made so far in this investigation is that direct comparison of only two variables is possible at one time.

In Text-fig. 10 the ratios L/T, T/B, and L/B are related in a scatter, the construction of which is explained in the Appendix. Logarithmic scales are used in order that all three ratios may be equally represented in the diagram.

Each shell is represented by a point which is plotted from the ratios of the measurements of T, B and L, on a grid formed by



TEXT-FIG. 7.—The relation between the width of the sulcus [W(s)] and the depth of the sulcus [D(s)] of the shells.

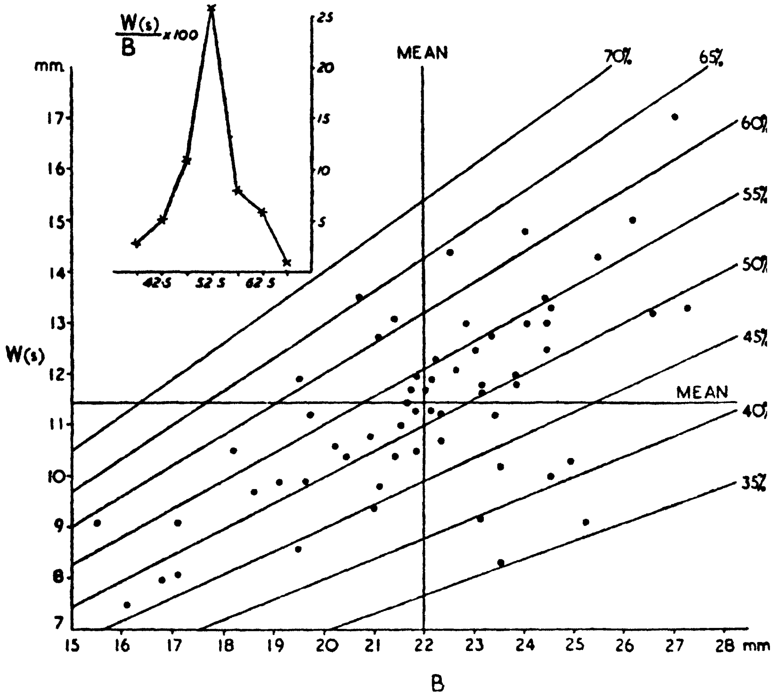
Inset : Frequency polygon of the ratios of these variables.

lines representing fixed values of L/T, T/B, and L/B (ratio lines). The position of each point thus depends on the relative values of the thickness, length, and breadth of the shell ; these values increase in the directions shown (at 120° to each other).

The relative degree of variation of each of the three characters is shown. The width of the scatter is greatest in the T direction, showing that the variation in proportionate thickness is greater than that in length or breadth. L/T and T/B, the two ratios that include the

variable T, have a wide range of values, while L/B has a narrow range (80 per cent of the shells lying between the lines L/B = 0·9 and L/B = 1·0).

To ascertain whether shells of the same general size tend to have similar relationships of the three variables, the shells have been divided



TEXT-FIG. 8.—The relation between the width of the sulcus [W(s)] and the breadth [B] of the shells.

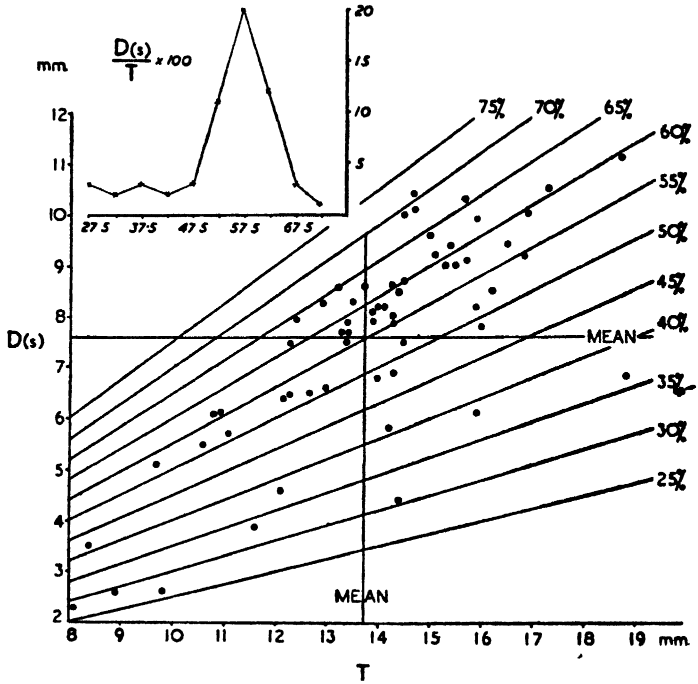
Inset : Frequency polygon of the ratios of these variables. Class marks of alternate intervals only are numbered.

into size-groups, the measure of the size being taken as the product of the values of T, B, and L for each shell.

The very small and the very large size-groups can be clearly separated on the scatter, the intermediate groups being to some extent intermingled. It is apparent that in small shells the proportionate length is greater than normal, while in the large shells it is less. It can be concluded therefore (if greater size is assumed to indicate greater age) that with growth there is more rapid increase in breadth and thickness than in length.

The close correspondence between the scatter produced by mathematical methods and that illustrated in Plate II which is based on a

subjective assessment of general shape, is illustrated in the inset to Text-fig. 10 ; this is essentially a reproduction of the inset to Plate II with the scatter divided into four groups. Since all the evidence of variation points insistently to the assemblage belonging to a single Linnean species, it should be emphasized that these divisions are used merely to assist comparison between the two scatters. Group A consists

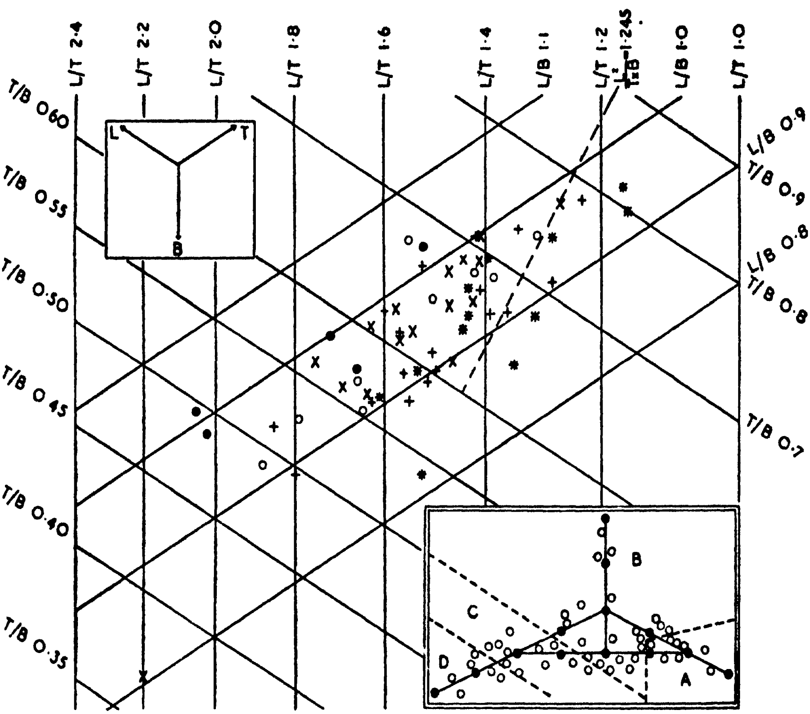


TEXT-FIG. 9.—The relation between the depth of the sulcus [D(s)] and the thickness [T] of the shells.

Inset : Frequency polygon of the ratios of these variables. Class marks of alternate intervals only are numbered.

of the more markedly triangular shells, and group D those with a rhomboidal outline. The shells of group C are intermediate between those of groups A and D but have a tendency to rhomboidal shape, while group B includes other intermediate types, and the rounded variants.

These subidivsions of the variants, with the exception of only three shells, are easily separable in Text-fig. 10. The actual lines of division correspond to ratio lines ; group D is separated from the remainder by the line T/B $=0{\cdot}55$; the line T/B $=0{\cdot}60$ passes between groups B and C. The majority of Group A is separated by a perpendicular



TEXT-FIG. 10.—The relation between the ratios L/T, T/B, and L/B of the shells. Length, breadth, and thickness increase in the directions indicated. The product of the values of T, B, and L is taken as a measure of actual size, and the following size groups are distinguished :—

●	. . . .	T × B × L less than 350 ;
O	. . . .	T × B × L 350 to 500 ;
×	. . . .	T × B × L 500 to 650 ;
+	. . . .	T × B × L 650 to 800 ;
✱	. . . .	T × B × L over 800.

The inset is a reproduction of the top left inset to Plate II, with the scatter divided into four arbitrary groups. In the main figure these four groups are, with the exception of only three shells, distinguishable as follows :—

Group A : T/B greater than 0·60 and $\frac{L^2}{T \times B}$ less than 1·245 ;

Group B : T/B greater than 0·60 and $\frac{L^2}{T \times B}$ greater than 1·245 ;

Group C : T/B between 0·55 and 0·60 ;

Group D : T/B less than 0·55.

An alternative means of locating the points in the scatter, which is more suitable when smaller numbers of shells are involved, is to plot the centres of the triangles formed by the lines of constant value of each variable passing through the appropriate point on the corresponding scale. This method will produce exactly the same scatter, but may involve the construction of triangles of inconveniently large size. This difficulty may be overcome to some extent by projecting the appropriate portions of the logarithmic scales on the sides of the original triangle (in this case triangle XYZ with scales 5–50) on to a smaller triangle within it (which may be enlarged as necessary). The values at the corners on each of the two scales concerned can be obtained by calculation.

EXPLANATION OF PLATES

PLATE II : VARIATION IN SHELL SHAPE IN A COMMUNITY OF *Goniorhynchia Boueti* (AUCTT.) FROM THE BOUETI BED, LANGTON HERRING.

The three variation series in shell outline (seen in dorsal aspect).

Top right inset : (1) *G. goniaea* Buckman ; (2) *G. contracta* Buckman ; (3) *G. boueti* (Davidson) 1878, figured for comparison.

Top left inset : Distribution of the remainder of the collection (white circles) on a framework of the main variant types illustrated (black circles).

Photographs and reproductions are $\frac{7}{8}$ natural size.

PLATE III : VARIATION IN THE SHAPE OF THE SULCUS IN A COMMUNITY OF *Goniorhynchia boueti* (AUCTT.) FROM THE BOUETI BED, LANGTON HERRING.

The letters correspond to the specimens illustrated in Plate II. Inset : (1) *G. contracta* Buckman ; (2) *G. boueti* (Davidson) 1878, figured for comparison.

Photographs and reproductions are $\frac{7}{8}$ natural size.

POSTSCRIPT

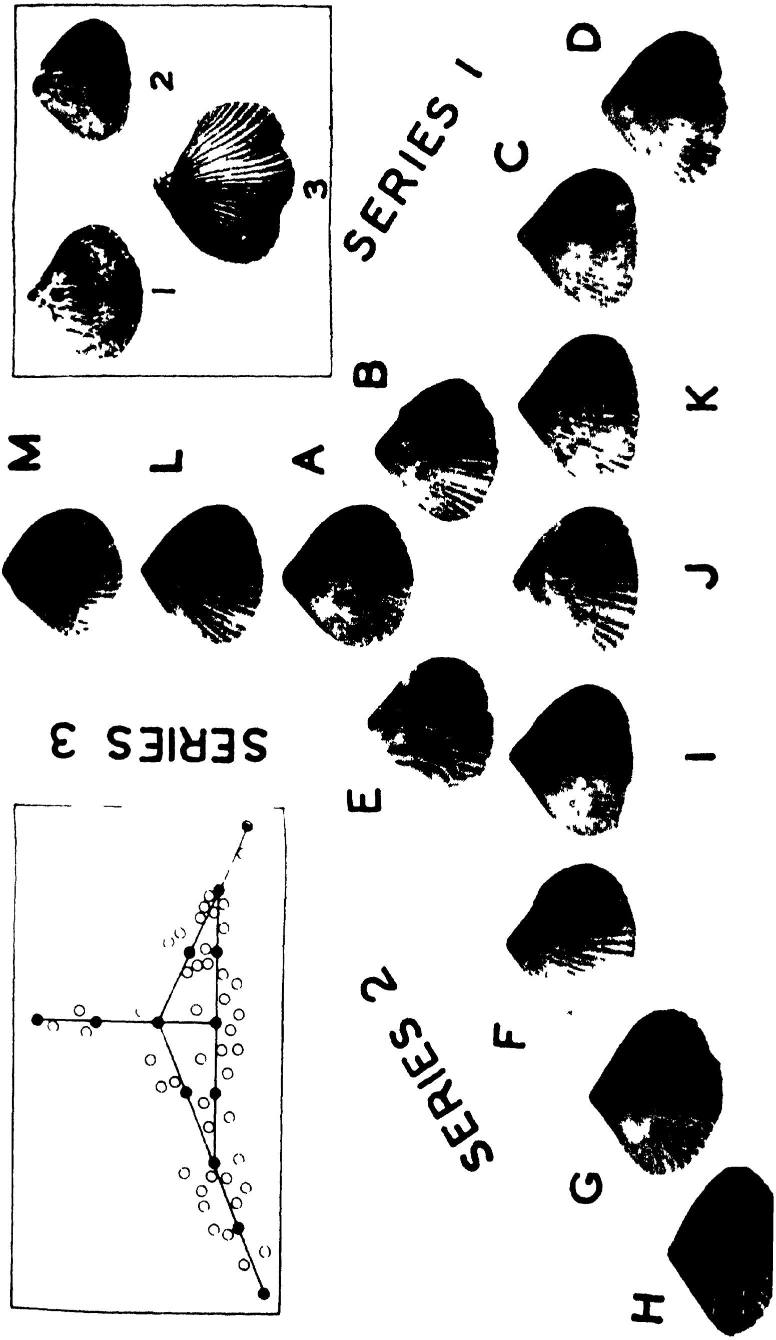
Since this paper was written two papers on *R. boueti* have been noted. These are :—

(1) ALKINS, W. E., 1923. *Mem. Manch. Lit. Phil. Soc.*, 67, pp. 109–120. Morphogenesis of Brachiopoda.

(2) MERCIER, Jean, 1937. *Bull. Soc. Linn. Normandie*, Caen (8) 9 (Travaux), pp. 33–5. Le Polymorphisme de *Rhynchonella boueti* Davidson.

Alkins gives frequency polygons for length, breadth, and thickness of four hundred specimens ; these closely compare with those in Text-fig. 2 of the present paper. In addition he shows the frequency polygons for B/L and T/L to be unimodal ; and he correlates L and B, and also L and T, and notes that the latter correlation is low.

The conclusions of the authors agree with those of both Alkins and Mercier in that they regard the shells assigned to *R. boueti* Davidson sensu lato as quite homogeneous in external characters.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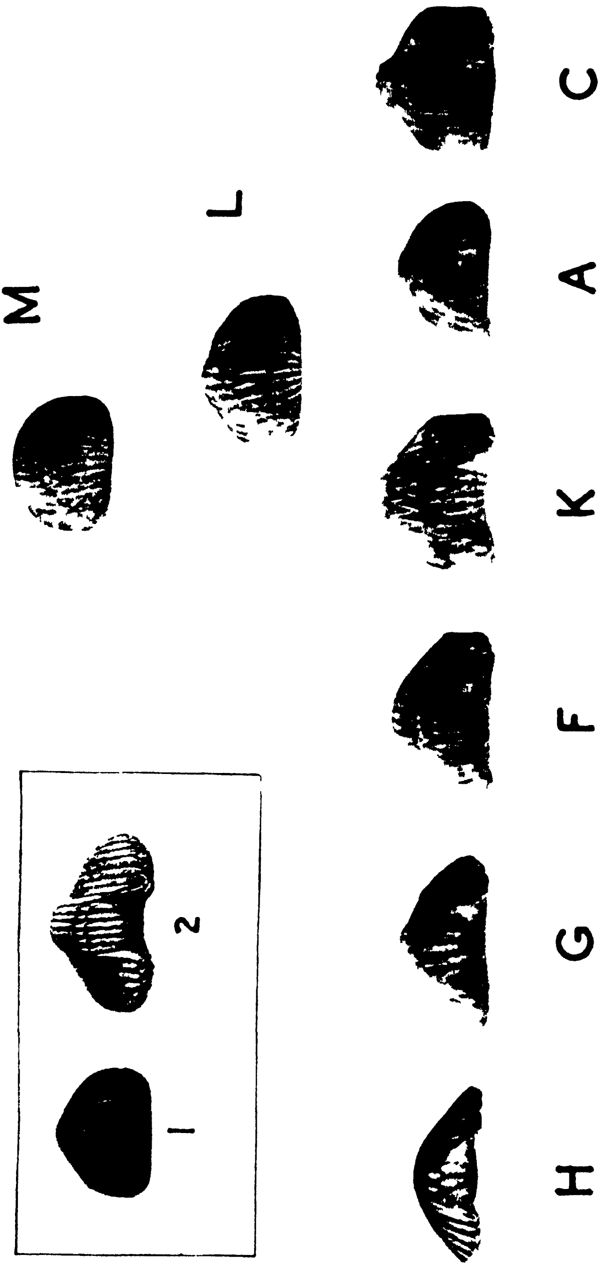


"VARIATION IN RHYNCHONELLA"

An Excavation revealing the junction between Ingletonian and Coniston Limestone at Ingleton

By Alan Wood

(PLATE IV)

WHILE conducting elementary field-classes in the Ingleton area it is not possible to show students any convincing grounds for separating the Ingletonian Series from the Coniston Limestone above. The field-evidence which so strongly impressed Hughes, Goodchild, Gunn, and Green, and which apparently convinced Aveline against his will,[1] still exists. In all three streams the highest beds of the Ingletonian are slates, which might be thought to show a gradation into the Coniston Limestone above, and the dip and strike of the Coniston Limestone appear closely similar to that of the near-by Ingletonian. Against these tangible facts arguments based on petrological similarities,[2] even the evidence of the Neptunian dyke,[3] are apt to seem slightly strained. Accordingly, during a field-excursion I suggested that an attempt be made to excavate the actual junction, and during the summer three students of Imperial College, Messrs. R. W. D. Elwell, G. J. H. McCall, and A. F. Trendall, have succeeded in laying it bare. To their enthusiasm and hard work the success of the attempt is wholly due. Owing to the kindness of Mr. W. S. Worthington, of Ingleton, the new exposure will be left open indefinitely.

The junction is only 5 feet to the north of the last visible exposure of Coniston Limestone below Pecca Falls, in the more westerly of the twin streams at Ingleton. It is 92 feet north of the point where the river narrows before turning to run along the plane of the North Craven fault. The Coniston Limestone, seen on the left of the photograph (Plate IV) strikes 141° east of north and dips at 41° to 43° to the south-west. Below are typical Ingletonian shales, green, soft, occasionally ribbon banded, and with some coarser-grained harder layers. Their strike is 129° east of north, the dip 73° to the south-west. Neither current nor graded bedding could be seen. Near the junction the Ingletonian rocks are cut at an acute angle by a thin film of white impalpable clay which strikes in a straight line at 133° east of north and dips at 50°–52° to the south-west. Closely associated with this clay layer is a hard band containing brecciated Ingletonian fragments in a calcite matrix. This lies now at one side of the clay film, now at

[1] J. G. Goodchild, *Geol. Mag.*, 1892, pp. 298–9.
[2] R. H. Rastall, *Proc. Yorks. Geol. Soc.*, 1907, pp. 87–100.
[3] W. B. R. King, *Quart. Journ. Geol. Soc.*, 1932, pp. 100–111.

the other. At the west end of the excavation this band closely underlies the Coniston Limestone, but at the centre of the excavation, some 3 feet to the east, it is separated from it by a lens of Ingletonian which thins in both directions. On the removal of blocks of Coniston Limestone a movement plane was *not* seen at the actual junction with the Ingletonian below. However, no basal conglomerate was present below the Coniston Limestone, and its basal beds, which are strongly silicified, yielded no fragments of Ingletonian on treatment with acid.

There can be no doubt that movement has taken place near the junction. The Coniston Limestone and Ingletonian are not otherwise broken up ; the latter in particular preserving its character in a remarkable way right up to the fault line, suggesting that the rocks were deeply buried at the time of fracture. Differential movement is to be expected at the junction of such dissimilar beds on their being folded together, and the throw of the fault is not necessarily great. The fact that faulting has occurred renders it difficult to assert positively that the junction is one of unconformity, but it would require an almost malicious set of circumstances to produce the observed differences of strike and dip in a conformable series. Furthermore, it must be pointed out that even though there has been movement near this junction, the evidence obtained is sufficient to dispose of the arguments based on surface exposures— there is no transition between the Ingletonian and the Coniston Limestone, nor is there identity of strike and dip at the contact. In future the onus must lie on those who seek to prove that the Ingletonian Series is not of Pre-Cambrian age.

EXPLANATION OF PLATE

The hammer rests on Coniston Limestone, its head on a quartz vein. A hammer length below is the junction with the Ingletonian. The difference in strike between the base of the Coniston Limestone and the thin bedded Ingletonian can be clearly seen. On the left-hand side of the photograph, near the bottom, is the white clay film in the Ingletonian. Above it is a fresh surface of Coniston Limestone, appearing lighter in colour than the weathered surface on which the hammer rests.

Junction of Ingletonian and Coniston Limestone

Outgrowths on Zircon from Southern Rhodesia

By Geoffrey Bond, National Museum of Southern Rhodesia

THE occurrence of what is probably clear secondary zircon on detrital grains of this mineral seems first to have been noticed by Butterfield (1936), in heavy residues from the Millstone Grit of Yorkshire. He showed that the outgrowths were too sharp and delicate to have withstood transport, and were, therefore, formed after the deposition of the rock. He also gave some account of their frequency and mode of occurrence in relation to the crystals to which they were attached. Smithson (1937) found similar outgrowths on zircons from the Middle Jurassic of Yorkshire, remarking that until we know of other occurrences it may be unwise to generalize, but that Butterfield's Millstone Grit zircons and his own Jurassic examples occurred in deposits which were either deltaic in origin, or closely associated with deltaic conditions.

The following notes record the occurrence of yet another example of detrital zircons on which secondary outgrowths have been seen. No complete evaluation is yet possible of the conditions which lead to their development, but evidence which seems to be relevant is given of conditions under which such outgrowths have and have not been found in Southern Rhodesian sediments. It is hoped that when a sufficient number of examples have been described, it may be possible to show that certain features are common to all occurrences. It is probable that many factors are involved, but the most important seem to be the nature and origin of the enclosing sediment. Its subsequent history, including depth of burial, disturbance by earth movements, and the proximity of later igneous activity, would also seem to be important. Evidence on these points is given for the occurrence described below, together with a brief comparison with the conditions under which Butterfield's and Smithson's examples were found.

The writer has examined heavy residues, prepared in the usual way with bromoform, from many samples of sandstones from the Karroo and Kalahari Systems of Southern Rhodesia, and a close watch has been kept throughout for signs of secondary changes, such as etched grains, outgrowths, and authigenic minerals. All the samples so far examined have been obtained from localities between Bulawayo and the Victoria Falls, a distance of over 200 miles. This stretch of country is occupied almost entirely by rocks of these two systems. Representatives of both occur near Bulawayo and again at the Victoria Falls. To the north of Bulawayo there is a stretch of country over 100 miles wide, in which the Karroo rocks are covered by loose sands

of the Kalahari System, until the Wankie Coalfield area is reached, in which Karroo sediments are again exposed.

The generalized sequence is as follows :—

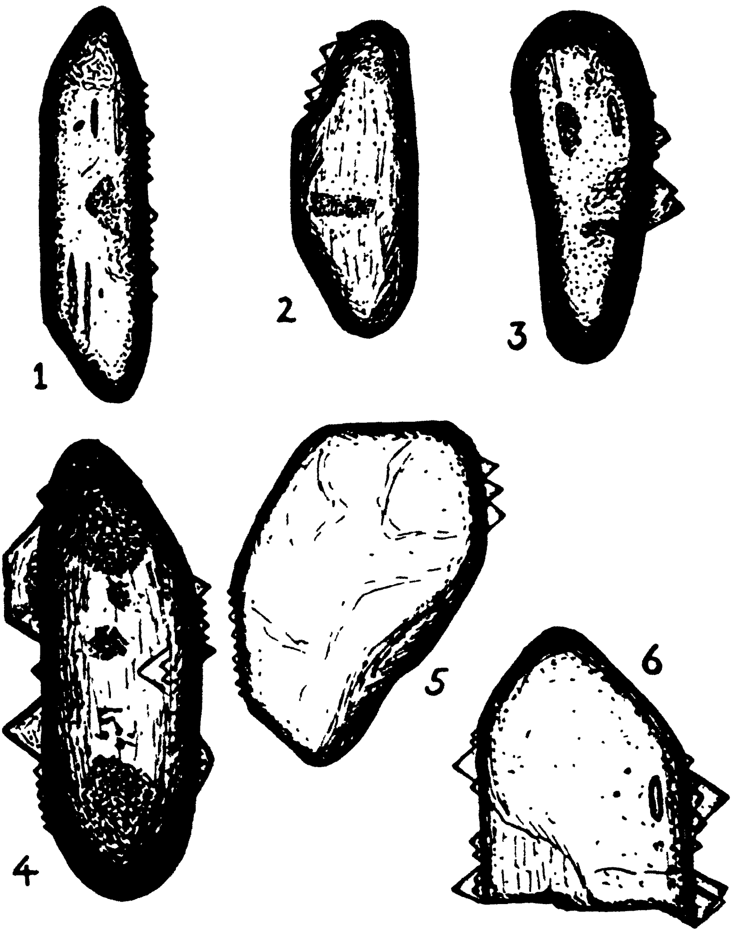
Kalahari Sands, up to 200 feet.			Pleistocene.
Unconformity.			
Basalts and sandstones. Probably Jurassic*			Karroo System
Forest Sandstone. 200 feet	Triassic		
Escarpment Grit. 300 feet			
Unconformity.			
Madumabisa Shales. 750 feet		Permian	
Upper Wankie Sandstone	450 feet		
Black Shale and Coal			
Lower Wankie Sandstone			
Strong unconformity.			
Pre-Cambrian Floor.			

The Karroo rocks of the Bulawayo and Wankie areas differ in horizon and lithology. In the Bulawayo district all the beds below the Forest Sandstone, which rests directly on the Pre-Cambrian floor, are missing. In the Wankie area the beds above the Escarpment Grit are missing, being cut out by the Deka Fault. The non-sequence at the base of the Escarpment Grit divides the Karroo sediments into a lower series deposited under subaqueous conditions and without associated lavas, and an upper series essentially of sub-aerial (aeolian) origin, containing interbedded lava-flows. This almost corresponds with the division of the rocks between the two areas. Post-Karroo movements have tilted and faulted the rocks in the Wankie Coalfield, whereas the Karroo rocks of the Bulawayo area are very nearly horizontal.

Zircons with outgrowths were first found in a separation from the Lower Wankie Sandstone from the Wankie Coalfield, and they are most numerous and best developed in that rock. They have also been found in the Upper Wankie Sandstone, where they are poorly developed and less frequent.

As may be seen from the figures (all from Lower Wankie Sandstone examples) these zircons closely resemble those illustrated by Butterfield and Smithson. The outgrowths are invariably of water-clear material and free from inclusions. In all cases they are attached to the remains of the prism faces. They range in size from minute points only visible by careful focusing under high power (as in Text-fig. 1, 1) to comparatively large growths easily visible under 1 in. objective.

Several varieties of zircon are present in the Lower Wankie Sandstone, and the grains are divisible into two crops. One consists of large grains up to 0·5 mm. with very little evidence of wear, and the other of very much smaller grains which are often very perfectly



TEXT-FIG. 1.

1. Clear purple zircon, with clear outgrowths. Length of grain 0·35 mm.
2. Dusky zircon with clear outgrowths. Length of grain 0·3 mm.
3. Pale yellow zircon, with clear outgrowths. Length of grain 0·325 mm.
4. Purple zircon, with clear outgrowths. Length of grain 0·4 mm.
5. Exceptionally clear zircon with outgrowths, showing their preference for prism faces. Length of grain 0·3 mm.
6. Purple zircon, broken during crushing of the specimens, yet with outgrowths undisturbed. Length of grain 0·25 mm.

All the above were drawn under $\frac{1}{6}$ in. objective, from specimen number A. 1865 in the Rhodesian Museum Collection, from the Lower Wankie Sandstone of the Wankie Coalfield.

rounded. Outgrowths occur on grains belonging to both series. The varieties water-clear, clear purple, dusky purple, yellow, and dusky;

either zoned or unzoned, are all present in both crops, and outgrowths have been seen on all except zoned dusky forms, though they seem to be most frequent on purple grains.

The preference for the prism faces can be seen from such examples as Text-fig. 1, 5, which is a grain of unusual shape, with very little left of the prism faces. Yet each short remnant is occupied throughout its length by minute outgrowths, which are not to be found in any other position. That these outgrowths are very securely attached to the grains can be seen from Text-fig. 1, 6, showing a grain which has been broken during the crushing necessary to reduce the sandstone. Although the grain has fractured the outgrowths have remained attached.

As in cases previously described the outgrowths are generally bounded by what appears to be $\{111\}$ and the angle $111 \wedge 111$, where measurable, is near the theoretical value. They are always in perfect optical continuity with the supporting grain.

The heavy mineral assemblage of the Lower Wankie Sandstone is restricted. Zircon (in the varieties given above) is the commonest mineral present, followed by tourmaline, rutile, biotite, and sphene, which is rare. All these occur in two district crops, large subhedral and small rounded. The shape characters of both heavy and light fractions support the field evidence that the sandstone is a subaqueous deposit. The description given by Lightfoot (1929, p. 25) leaves little doubt that it accumulated in shallow water. This was undoubtedly fresh, since no marine incursions are known in Karroo rocks in this part of Africa. The Wankie sediments accumulated near the southern margin of a large basin of deposition, but the direction from which the material was derived is not known. None of the other minerals present shows any trace of solution etching, or of secondary outgrowths. The suite is poor for subaqueous deposit, and the minerals are mainly of species stable in sediments (Smithson, 1941).

The heavy assemblage of the Upper Wankie Sandstone is rather different. Zircon is the commonest mineral, but only water-clear and dusky forms are present, the latter being the less abundant. Rutile and tourmaline are fairly frequent, while chlorite and monazite are very rare. Zircons with outgrowths are fewer and more feebly developed than in the Lower Sandstone, but they are to be found on both varieties present. None of the other minerals, which are again mainly stable species, show any secondary changes. Again there are two crops of all the minerals, but the rounded grains are relatively fewer in number. The light and heavy fractions, and Lightfoot's description (op. cit., p. 33), again suggest that the sandstone was formed in shallow fresh water.

A Karroo sandstone from Bumboosi, some miles south of the

Wankie Coalfield, has been examined. Its horizon is doubtful (probably Stormberg), but it is a subaqueous deposit, and probably belongs to one of the divisions of the Karroo rocks found in the Wankie Coalfield. In hand specimen and mode of weathering it resembles the Upper Wankie Sandstone, but the heavy mineral suite is quite different. The Bumboosi residue consists of zircon, garnet, tourmaline, rutile, and epidote, in that order, with rare hornblende, chlorite, monazite, apatite, and biotite. The suite is therefore richer, and contains more "unstable" species than those from Wankie. There are no outgrowths on the zircons, but the ends of many of the rutile grains show delicate needle-like projections, in optical continuity with the crystals, which must be either due to secondary growth or deep solution etching. A few tourmalines show a similar raggedness. No igneous rocks are known in the neighbourhood, the rocks are apparently little disturbed, and the minerals typically liable to secondary changes by solution are unaltered.

Other residues examined include specimens from several horizons in the Forest Sandstone, all the sandstones interbedded with lavas in the succeeding division, and many samples of sands of the Kalahari System. All are sands of desert origin, undisturbed by tectonics, though some of the Karroo specimens have been much baked by overlying thick flows of basalt. All contain zircon as their most abundant mineral. Most of them contain notable amounts of rutile, garnet, staurolite, kyanite, epidote, and sphene. None of them have produced zircons with even the minutest trace of outgrowths. The only suggestion of instability was found in staurolite and kyanite from a sample taken just below the base of a thick lava (Bond, 1943).

It has been suggested that the secondary material is not in fact zircon, but some isomorphous mineral. Under the microscope, however, it is not possible to distinguish the material from zircon.

It has also been supposed that such an appearance could be caused by the breaking down during transport, of the outer layers of strongly zoned crystals. Many of the grains to which outgrowths are attached show no trace of zoning and their sharp terminations are in strong contrast to the rounded outline of the supporting grain. One is forced to conclude that the material, whatever its composition, is authigenic. The observation that the outgrowths are always water-clear and free from inclusions, irrespective of the type of grain to which they are attached, indicates that they were all formed under similar conditions. The supporting grains being of several varieties must have originated under slightly differing sets of conditions.

It is still unwise to generalize from a few cases, but it seems clear that zircons in sandstones of aeolian origin have no tendency to develop outgrowths. In the case of the Triassic sandstone mentioned

by Smithson (1941), outgrowths were only found where the sandstone was in contact with the Cleveland dyke. In Southern Rhodesia, zircons from aeolian sands, even where they are in contact with thick lava flows, do not seem to acquire secondary material.

It is impossible to assess the effects of deep burial and tectonic disturbance in the case of the Wankie specimens, since the sedimentary record in this part of Africa is very incomplete, but they are unlikely to have been buried under many thousands of feet of strata, since the post-Cretaceous history of the region has largely been concerned with denudation. Their association with a rather meagre suite of heavy minerals is perhaps important, in connection with which the absence of garnet from the Wankie Sandstones and its abundance in the Bumboosi specimens may also have some significance.

The occurrences noted so far have at least one feature in common. They have all been found in non-marine sediments, which suggests that cognate fresh, or perhaps slightly brackish, water may be necessary for their growth. The parts played by subsequent tectonic history, and other as yet unknown factors must remain obscure until many more cases have been investigated.

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The Plio-Pleistocene Boundary and Mammalian Correlation

By H. B. S. Cooke (Johannesburg, South Africa)

THE problem of the boundary between the Pliocene and the Pleistocene is still very far from satisfactorily settled both from a geological and from a faunal viewpoint. It becomes increasingly apparent that the two aspects of the problem require different definitions and in consequence there has been very great confusion in the application of the terms " Pleistocene " and " Quaternary " both in geological and in palaeontological literature. The original definitions of these terms, too, seem very largely to have been forgotten and they have been used by a variety of writers for various purposes.

The difficulties were discussed at length at the First Pan-African Congress on Prehistory, which met at Nairobi in January, 1947, and a special sub-committee comprising a number of leading geologists and palaeontologists formulated a resolution which was adopted unanimously in plenary session. It was stated that the Congress " recognizes the great difficulty in applying to Africa the standard European geological terminology for the period just before, during, and after the Eurasian ice age and recommends that: (1) Africa should be treated for the time being as a geological unit distinct from Europe for this period and an African nomenclature should be used for the deposits and faunas of the period in this continent, excluding the north African littoral. (2) The established succession of deposits and faunas in East Africa should be used as a basis for the development of the African terminology ", and goes on to detail the stratigraphic units to be recognized. While adoption of this resolution is very helpful in studies within the African continent it does not in any way assist in solving problems concerning correlations between Eurasian and African faunas and deposits. The barrier seems to lie in the confusion in usage of terms outside Africa as well as within it and the time is ripe for a general reconsideration of the problem.

The term " Quaternary " was originally proposed by Desnoyer (1829) for a group of marine deposits more recent than the Tertiary beds of the Seine and this term has been widely adopted to designate a separate period which, with the Tertiary, comprises the Cainozoic era. Four years later Lyell (1833) proposed certain sub-divisions of the Tertiary into the present systems and he subsequently introduced the term " Pleistocene " for part of the latest phase of that period. In 1863, however, he repented of this in the following terms: " In 1839 I proposed the term Pleistocene as an abbreviation for Newer Pliocene, and it soon became popular, because adopted by the late

Edward Forbes in his admirable essay on 'The Geological relations of the existing Fauna and Flora of the British Isles' but he applied the term almost precisely in the sense in which I shall use Post-pliocene in this volume and not as short for Newer Pliocene. In order to prevent confusion I think it best entirely to abstain from the use of Pleistocene in future." The term has, however, not been dropped but has been widely adopted in Forbes's sense. Most authorities recognize the most recent part of the Quaternary as the Holocene and regard the remainder as constituting the Pleistocene. Others, however, regard the Pleistocene as embracing the whole of the Quaternary and the terms may even be used as synonyms. In point of fact the term Pleistocene is equivalent in value to such terms as Miocene and Pliocene, and Quaternary is equivalent to Tertiary, so that Pleistocene and Quaternary should not be used interchangeably.

As originally defined, the Pliocene, Miocene, etc., were convenient *zones* of the Tertiary based on the proportions of living types of marine invertebrates present in the different strata. Subsequently, however, the terms were applied to the rock groups themselves and the original faunal boundaries were somewhat modified. The terrestrial faunas of the corresponding rock groups were then studied and the present tendency is for mammalian faunas to be used for the sub-division of Tertiary and Quaternary deposits. Since the changes or breaks represented in the mammalian faunas did not always correspond with the rock groups, the boundaries of the Miocene, Pliocene, etc., have been moved about from time to time until it is now virtually impossible to trace their exact connection with the original marine zones. As far as the Tertiary is concerned, however, geologists and palaeontologists have usually been able to reach some accord in selecting a distinctive lithological and faunal break as the commonly accepted boundary. The Plio-Pleistocene boundary, however, is still the subject of considerable dispute and, very often, of somewhat acrimonious discussion. Indeed, it becomes increasingly apparent that any definition which suits the geologist does not accord with the demands of the palaeontologist and vice versa.

In 1911 Haug suggested that "le Quaternaire . . . est nettement séparé du Néogène par l'apparition brusque de plusieurs genres inconnus dans le Néogène, au moins en Europe, en particulier, parmi les Mammifères, *Elephas*, *Equus*, *Bos*". This definition has many apparent advantages and has been restated by Hopwood (1935) who suggests of these genera "that the presence of any one of them is a sufficient reason for assigning a Pleistocene age to the bed in which it is found". In 1938, however, in an Appendix to a paper by Pilgrim, Hopwood pointed out some of the difficulties in the way of employing this definition in India, yet two years later (1940) he still applies it in

Europe in default of a better solution. Pilgrim (1944) has recently emphasized some of the difficulties and shown that from a geological aspect it is best to draw the base of the Pleistocene at the commencement of the first important and generally observable glaciation (Günz, Nebraskan, Bain Boulder Bed, etc.). This viewpoint has been adopted by Zeuner (1945) in the latest comprehensive survey of the Pleistocene and, despite the fact that there are some indications of earlier glacial episodes, it has much to recommend it as the best *geological* boundary. It may well offer the best prospect of world-wide correlation on a basis of changing sea levels or changing climates.

If this boundary is accepted, however, Haug's boundary falls somewhere within the later Pliocene and there is not necessarily any marked faunal break between the Pliocene and the Pleistocene corresponding to the onset of glacial conditions. On the other hand, it now appears that the same argument of indefiniteness of the boundary would apply also to acceptance of Haug's criterion, for there are cogent reasons for not recognizing the first appearance of *Equus*, *Elephas*, or *Bos* as simultaneous all over the world. As the mammalian faunas of Africa become increasingly well known it grows more and more apparent that the course of events in this continent was much less markedly conditioned by climatic changes than in Eurasia and that there has existed for a long period an essentially African fauna developing at least partly independently of the Eurasian one and affected somewhat differently by migrant forms. In southern Africa, at any rate, it seems probable that *Equus* arrived in a differentiated state at a period later than its appearance in India and Europe and that the differentiation of the zebrine horses took place largely in Africa itself. It seems clear, too, that at least some degree of elephant evolution occurred within the continent and also, incidentally, that the African types of pig had a local evolutionary history. Furthermore, the *Bos* family is not represented in the African fauna until the appearance of *Bubalus* in association with moderately advanced human industries. *Syncerus* is not acceptable as a substitute for *Bos*.

The degree of confusion resulting from the different usages of the terms Pleistocene by different authorities is frequently apparent in the literature. For instance, Zeuner (1945, p. 215) gives Hopwood's views on the faunal divisions of the East African " Pleistocene " into Lower, Middle, and Upper without, apparently, realizing that Hopwood employed Haug's faunal definition and regarded the Villafranchian as Pleistocene whereas Zeuner himself (pp. 175, 257) accepts the European geological definition and places the Villafranchian in the Pliocene !

It thus seems that any attempt to use the term " Pleistocene " in a faunal sense is bound to result only in further confusion, especially

when it is applied to Africa. The solution seems to lie in the deliberate abandonment of the term Pleistocene to its proper place as a stratigraphic term and the adoption of distinctive stage names for purposes of faunal correlation.

In 1937 the Vertebrate section of the American Paleontological Society proposed to set up a provincial time scale for the Tertiary " not as an attempt to secede from the standard international time scale, but to permit accurate and exact expression of the existing possibilities for correlation of mammal-bearing beds, without confusion with the less exact correlations possible between them and the marine sequence " (Wood, H. E., 1941). It is also observed that " If it becomes virtually impossible to convey the exact results obtained with any certainty of being correctly understood, it is clearly time either to modify or replace the outgrown terminology ". Surely this is only too apt a description of the present usage of Pleistocene, but in this instance the confusion is on a world-wide scale ! It is rather remarkable that, while all other periods have by now been divided into faunal stages, the Pleistocene has never been so divided and in the 1941 American report this stands out in the correlation chart as an obvious departure from uniform practice. Possibly the relatively short duration of the Pleistocene has prompted this attitude but the necessity for stage names should be dictated more by rapidity of faunal change than by actual time and on these grounds the Pleistocene has as good a case for consideration as has the Pliocene. The American report terminates the Pliocene at the Astian stage.

The term " Villafranchian " is already widely used as a term for correlation of mammalian faunas and embraces the earliest fauna which generally includes *Bos*, *Equus*, and *Elephas*. The Pinjor of India, the Nihowan of China, the Broadwater, etc., of North America, and parts of the Crag of the British Isles are almost unanimously recognized as Villafranchian. They are late Pliocene on Pilgrim's and Zeuner's definitions but Pleistocene according to the views of Hopwood and of Colbert (1935). Provided we recognize the *characteristics* of the fauna, however, and agree regarding its *relative* age in the Tertiary-Quaternary sequence it seems immaterial where we place the precise geological boundary. The American report (Wood, 1941) on the proposed Tertiary stages makes the same point in regard to geological boundaries, saying " there is no intention or hope on the part of the committee of deciding, for example, where the Pliocene-Miocene boundary ' really ' is. The committee specifically disclaims any supernatural sources of information regarding this or any other controversial problem. One of the incidental advantages of the proposed terminology is in making it easier to sidestep such controversies when they are irrelevant to the problem in hand, since

Barstovian should be equally intelligible wherever the Pliocene-Miocene boundary might be drawn ".

Unfortunately there are no areas of the world so far known where there is a continuous sequence of deposits representing the entire post-Villafranchian and so no equivalent stage name of similar definition presents itself. It would doubtless be possible to select several stage names for sections of the post-Villafranchian but these would mostly be from glaciated areas and when one integrates the faunas covering the whole of this period of time in the extra-glacial regions it seems that there has been a fairly general steady and gradual evolutionary advance accompanied by progressive extinction of the larger archaic types. In the glacial areas the faunas most probably present a false impression of distinctness as a result of migrations and climatic adaptations which are not a true reflection of the processes going on in the extra-glacial areas. It thus seems reasonable, as a starting-point at any rate, to recognize a single major faunal stage for the post-Villafranchian, ending with the rather widespread extinctions which mark the beginning of the Holocene. If this faunal stage be recognized, then local sub-stages such as the Cromerian or Sicilian may be placed in their proper *faunal* perspective.

It may be argued that such a step is not necessary as the Villafranchian is generally agreed to be pre-Glacial and that on Pilgrim's and Zeuner's definitions the post-Villafranchian is accordingly Pleistocene. It is felt most strongly, however, that it is essential for future progress that a new term be developed for faunal use which can be divorced from " Pleistocene " until such time as there is general and satisfactory agreement upon the definition and meaning of the term. It is also important to distinguish between the methods of geological correlation on physical grounds and the homotaxial equivalence implied by faunal stages. This is of particular importance in the " Pleistocene " where migration plays a most significant role. There can be little doubt that further geological work will tend to shift the Plio-Pleistocene boundary stratigraphically and further palaeontological researches will inevitably modify our present conceptions of the faunal stages and sub-stages. It is unlikely that the two different approaches will result in shifts of boundaries to the same degree and in the same sense. If we accept faunal stages it is immaterial to faunal considerations where the current geological boundary be placed and faunal discussions need not be confused with geological ones. Such vague terms as " Lower Pleistocene fauna " will tend to disappear. At present Lower Pleistocene fauna means Villafranchian to most American geologists but indicates early glacial to the European worker. All are nevertheless agreed that the Villafranchian is pre-glacial. It may also be mentioned that it has long been the practice in

pre-historic archaeology to use a special set of stage terms to define human material cultures within the Quaternary quite regardless of geological sub-divisions, though taking full cognisance of stratigraphic considerations for local sequences.

As has been pointed out, it is virtually impossible to select at this juncture a stage name for the post-Villafranchian-pre-Holocene period which is at all equivalent in definition to such terms as Pontian, Astian, Villafranchian, etc. It has been demonstrated, however, that some term seems to be a vital necessity for future progress and one of different definition may therefore be proposed for the time being. It is notable that no human tools have so far been found with a Villafranchian fauna whereas there is abundant evidence of human industry fom the beginning of the post-Villafranchian and that this period was the main one of human development and expansion. It is therefore proposed to designate it the *Adolescian* as an indication that it was during this period that man grew up and that our present mammalian fauna was also then in course of formation. The late fauna which is made up almost exclusively of living mammals may be referred to a stage designated *Novian* as an indication of its essentially modern character. This will be roughly equivalent to the Holocene of some authorities.

On the new and somewhat unorthodox scheme here proposed, Early, Middle, and Late Adolescian faunas will be roughly equivalent to Zeuner's Lower, Middle, and Upper Pleistocene but no direct correlation will be implied. It is considered that the subdivision of faunas in glaciated areas into a rather large number of faunules is *not* justified except in a purely geological sense as horizon faunas useful in local correlation and owing much to their particular climatic environments and to migration. It is felt that recognition of the importance of separating faunal and stratigraphic terms will lead ultimately to greater progress than the formulation of any rigid (and necessarily artificial) definition for the Plio-Pleistocene boundary which is at present expected to serve alike for both studies. It also seems that increasing interest attaches to the study of mammalian faunas *away* from the glaciated areas as the source regions *from* which migrations extended as a consequence of climatic controls. The great peculiarities of the period in which climatic changes have played so significant and important a role in upsetting " normal " theories of uniform evolution and steady migration of faunas are considered to warrant the somewhat unusual course now suggested. Adoption of these proposals should open the way both to better geological correlations and to better faunal comparisons than has been possible in the past when a single term has been overworked and misused for both purposes.

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Scytalocrinus seafieldensis sp. nov. and a rare *Ureocrinus* from the Carboniferous Limestones of Fife; with Notes on a Blastoid and Two Crinoids from the Carboniferous Limestones of the Clitheroe area

By JAMES WRIGHT

(PLATE V)

DURING a recent visit to Fife I was so fortunate as to find in the Seafield Tower Limestone, on the shore at Seafield near Kirkcaldy, two rare crinoids, one of which belongs to a new species of *Scytalocrinus* and is described herein. The other is a specimen of *Ureocrinus bockschii* (Geinitz) which has part of the column and three arms attached to the cup. Although cups of this species are common at various horizons in the Scottish Carboniferous limestones, this is the first example in this state of preservation to be recorded from rocks north of the Forth, other specimens previously noted all occurring on the Scottish border near Penton Linns in Roxburghshire (Wright, 1939–1940, Wright and Strimple, 1945).

In a recent paper (Wright, 1947) the blastoid *Orophocrinus pentangularis* (Miller) was recorded from Coplow Knoll, Clitheroe, and comment was made on this being the only authenticated record of a blastoid from the locality. By one of those unexpected happenings which add to the charms of collecting, another blastoid was discovered at Coplow during the past summer. The species, however, is different from that found last year and belongs to *Orophocrinus verus* (Cumberland). Since this is only the second blastoid to be noted at Coplow its occurrence seems worthy of recording here.

On looking over some old collections made many years ago at the neighbouring quarry of Bellman, a specimen of a *Platycrinites* turned up and cleaning has disclosed its identity with *P. bellmanensis* Wright. In the description of that species, however, doubts were expressed as to whether the cup plates were originally ornamented or not, both holotype and paratype being much weathered (Wright, 1942, p. 270). It turns out that the plates have a strong granular ornamentation and this is shown on the specimen now illustrated on Pl. V, figs. 7–10. A young example of *P. gigas* Phillips was also recently found at Coplow and is shown on the accompanying plate.

SCYTALOCRINUS Wachsmuth and Springer

Scytalocrinus seafieldensis sp. nov.

Pl. V, fig. 6

Crown of medium size; cup somewhat low, turbinate; IBB visible in side view; BB conspicuous, about twice as high as IBB; RR about

same height as BB, two times as wide as they are high, somewhat rounded and each R curving inwards to meet adjoining RR ; sutural areas between RR and PBrBr gaping ; PBrBr one, approximately one and a half times higher than RR, full width at base where they joined RR but tapering distally ; arms uniserial, forking once on PBrBr ; $PBrBr_2$ rather thick proximally, becoming thinner distally, tending to be cuneiform and bearing strong pinnules ; arms rounded, stout to near middle height after which they taper finely to distal ends. Plates smooth or finely frosted.

Holotype.—J. W. Coll. No. 1546, Plate V, fig. 6.

Horizon and Locality.—Scottish Lower Limestone Group, Seafield Tower Limestone, Seafield shore, west of Kirkcaldy, Fife.

Dimensions of Holotype.—Full length of crown, 66 mm. ; height of cup, 5·7 mm. ; width of cup across RR, 11·6 mm.

Remarks.—As may be noted from Pl. V, fig. 6, the holotype consists of a crown showing three rays well exposed, the middle one perhaps being the finest. The left ramus of right ray with its attached pinnules is also finely preserved. Unfortunately, it is not possible to state the orientation of the crinoid, as the anal inter-radius (assumed to be of normal character), and two of the radials are buried in the matrix which is a very hard crinoidal limestone. Our specimen, however, comes well under the definition of *Scytalocrinus* and there seems no question of its relationship to other species of the genus. Among described species the Seafield form appears to come nearest to *S. validus* Wachsmuth and Springer (W. and S., 1897, pl. vii, fig. 2, Springer, 1926, pl. 17, fig. 8), and *S. decadactylus* Meek and Worthen (M. and W., 1866, pl. xvii, fig. 6). In its general habitus *S. seafieldensis* probably more closely resembles the former than the latter species. The cup, however, in the new Fife species differs from the two American forms, from *S. validus* in the more conspicuous infrabasals and from *S. decadactylus* in the less prominent nature of these plates and in the relatively lower radials. In the shape of the cup therefore our new species seems to occupy an intermediate position between the two American forms mentioned. The primibrachs also appear to be relatively higher in *S. seafieldensis*, and the arms generally, while having a close resemblance to those of *S. validus*, seem to taper more gracefully towards the distal extremities. Although it is not possible to state which of the exposed rays is the anterior, one of them must occupy this position. In *S. validus* it is apparently quite usual to find the anterior ray carrying one arm only. There is of course no indication of this in the Seafield form, but it would be rash to think that other specimens of the species might not show this character. No trace of the ventral sac is preserved and the column has disappeared although the proximal columnal is still attached to the cup.

UREOCRINUS Wright and Strimple

Ureocrinus bockschii (Geinitz)

Pl. V, fig. 5

The cup in this specimen is typical of the majority of examples of the species found in the Scottish limestones. Unfortunately the anal side is hidden in the matrix so that it is not possible to say whether in this respect it is normal for the species, i.e. with large RA surmounted by two small plates, or one of the variations from this. The height of the cup is 12 mm. (approx. ½ in.). Contrasted with this is the great length of the arms, three of which can be traced to near their extremities. The middle arm is the most complete and measures 73 mm. (approx. 2⅞ in.) in length. Owing to the arms being embedded very unevenly on the hard and carious surface of the limestone it has not been possible to develop them as well as could be wished or to show them more distinctly in the photograph. In the specimen itself traces of the pinnules can be seen here and there and are fairly well preserved on the right arm near its termination. Part of the column, 10·3 mm. in length, is attached to the cup. It is round, uniform in width throughout, and consists of fifteen columnals. The proximal columnal is less than 1 mm. thick and is followed by somewhat thicker columnals. Lower down these alternate with others of a thinner nature. Including the present specimen there are now known six individuals of *Ureocrinus bockschii* with arms more or less well preserved. All are from Penton Linns, Liddesdale, excepting the Seafield specimen now recorded. The location of all these specimens is as follows :—

3 specimens from Penton Linns	J. Wright Coll., Nos. 2123, 2345, 2190.
1 specimen „ „ „	Begg Coll., Hunterian Museum, University, Glasgow, No. E3435.
1 „ „ „ „	(Collected by Mrs. Longstaff) British Museum (Nat. Hist.), Geol. Dept., No. E25370.
1 „ „ Seafield	Now figured, J. Wright Coll., No. 1546.

In none of the Penton specimens are the arms so well preserved as to length as in the Seafield specimen. One or two show the proximal region in perhaps better detail, but the distal portions have disappeared. Besides giving us a better idea of the full length of the arms the Seafield specimen further emphasizes the single unbranched character of these elements in *Ureocrinus*.

OROPHOCRINUS VERUS (Cumberland)

Pl. V, figs. 1–3

This specimen is in a fair state of preservation and appears to be typical of the species originally figured by Cumberland (1826, pl. B, fig. 1) and described later from other specimens by Etheridge and

Carpenter (1886, pl. xv, figs. 1–4). Specimens described by the latter authors are stated to come from Whitewell in Bolland (presented by J. Rofe) and Preston, Lancashire. Cumberland says his specimen came from the borders of Lancashire and Yorkshire and may have been found in the Clitheroe area. Our specimen occurred in Coplow Quarry at the east end of the section and probably on or about the same horizon as that of the specimen of *O. pentangularis* found last year. The latter occurred in a bed at the west end of the quarry. This, however, is probably the extension of the same bed across the quarry floor.

PLATYCRINITES BELLMANENSIS Wright

Pl. V, figs. 7–10

In its general characters the present specimen (J. W. Coll. No. 2383*c*) agrees well with holotype and paratype (Wright, 1942, pl. xi, figs. 9–12, 13–16), its chief distinction and reason for recording here being the well-preserved ornamentation of the plates. Both holotype and paratype are much weathered and the plates are almost smooth. In the present specimen, all cup and inter-radial plates are studded with prominent and somewhat coarse granules or pustules. The species itself appears liable to some distortion. In holotype and paratype the tegmen has a bulge to the left lateral side. In the new specimen, when looked at sideways, the tegmen is bulged to the posterior, with the result that the anterior portion of tegmen is lower than the posterior. The specimen is somewhat larger than the holotype and the tegminal plates are more numerous, otherwise there is little difference in the three specimens.

PLATYCRINITES GIGAS Phillips

Pl. V, fig. 4

The specimen illustrated is a young individual of *P. gigas* Phillips similar to others which occur at Coplow. It is notable here only because the anal tube is intact and shows the spines surrounding the summit of tube. Many specimens of this species occur at Coplow, but with tube generally broken off at the contraction of the tegmen.

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EXPLANATION OF PLATE

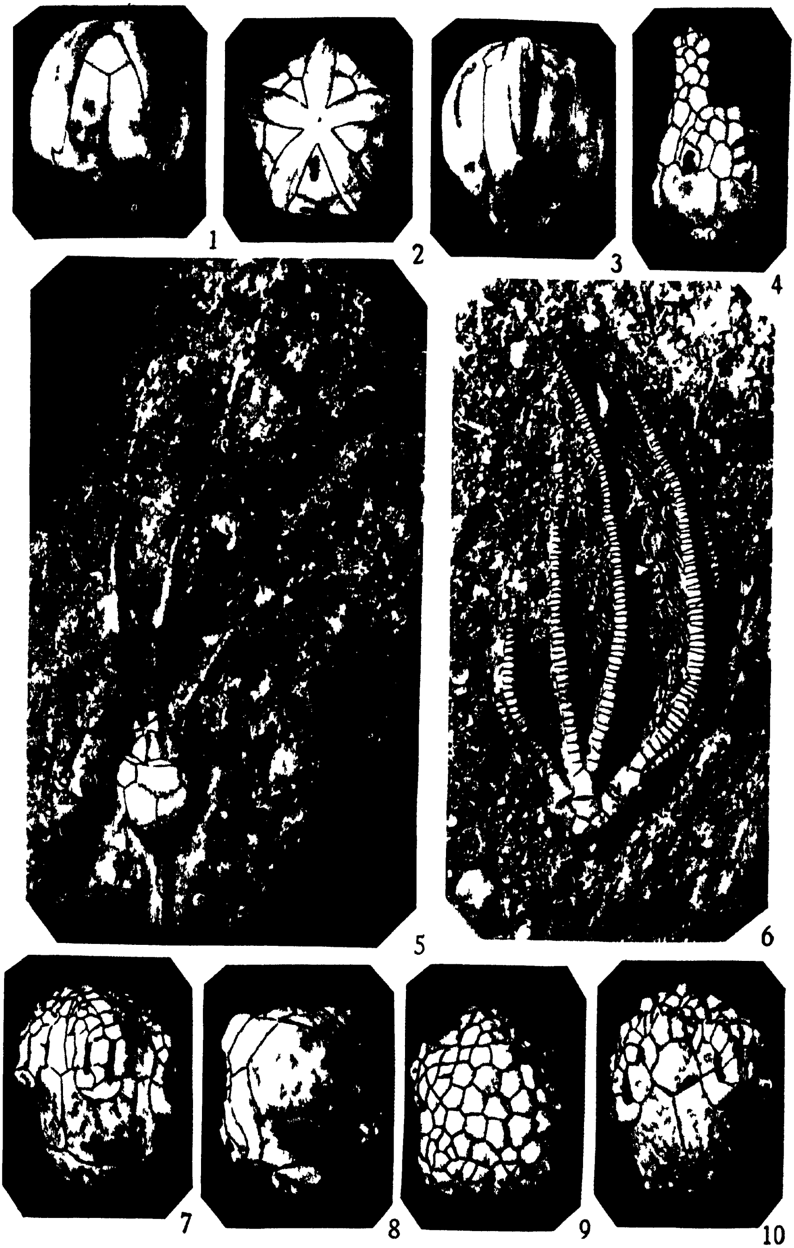
FIGS. 1–3.—*Orophocrinus verus* (Cumberland), posterior, summit and anterior views of specimen from Coplow Knoll, Clitheroe ; J. Wright Coll., No. 1693. × 1½.

FIG. 4.—*Platycrinites gigas* Phillips, a young specimen from the same locality, right antero-lateral view ; J. Wright Coll., No. 1695, × 1½.

FIG. 5.—*Ureocrinus bockschii* (Geinitz), specimen with part of the column and three arms attached from the Seafield Tower Limestone, Seafield shore, west of Kirkcaldy, Fife ; J. Wright Coll., No. 1547. Nat. size.

FIG. 6.—*Scytalocrinus seafieldensis* sp. nov. side view of the holotype from the Seafield Tower Limestone, Seafield shore, west of Kirkcaldy, Fife ; J. Wright Coll., No. 1546. Nat. size.

FIGS. 7–10.—*Platycrinites bellmanensis* Wright, anterior, basal, summit and posterior views of new specimen from Bellman Quarry, Clitheroe ; J. Wright Coll., No. 2383c. × 1½.



J. Wright Photo

CRINOIDS AND A BLASTOID FROM THE CARBONIFEROUS LIMESTONES OF FIFE AND LANCASHIRE.

CORRESPONDENCE

THE AGE OF THE HIGHLAND SCHISTS

SIR,—Dr. J. G. C. Anderson's comprehensive account of the Highland Border rocks (*Trans. Roy. Soc. Edin.*, 1947, 61, 479) appears to take us several steps towards a dispersal of the depressing mists of conflicting opinions which have too long enveloped the Highlands.

The following more recent developments all have an important bearing on the subject: the vindication of Sir Edward Bailey's Islay and Loch Awe sequences by Dr. Allison; Sir Edward's acceptance of Mr. Carruthers's extended Eilde Flag-Dalradian sequence in the Lochaber country, and his abandonment in the light of Dr. McCallien's work in Donegal of the elusive slide between the Islay and Loch Awe successions; Dr. Richey and Professor Kennedy's elucidation of a Sub-Moine complex in Morar which appears to put the reality of some, at least, of the much debated Lewisian inliers in the Moines beyond question; Professor Read's demonstration of the order of deposition in the Banffshire Dalradians; and Mr. Hartley's of the Llandeilian age of the highest Border Rocks in Tyrone and of the importance in that area of intra-Ordovician orogeny and intrusion. Dr. Anderson now synthesizes the evidence along the Border Fault, and amongst other things gives the death blow to Gregory's unpopular Lennoxian.

Not least in importance of recent advances has been Dr. Pringle's discovery of trilobites in the Leny Limestone, on the basis of which Dr. Anderson claims a Cambrian age for the upper part, at least, of the Dalradians. If the latter pass downwards conformably into the Moines it would seem that they must cover not only all Middle and Lower Cambrian times, but something of the interval between Cambrian and Torridonian as well, and Peach's view of the equivalence of Torridonian and Moines is correspondingly strengthened.

There is a corollary to Dr. Anderson's theorem of Cambrian Dalradians to which attention may be drawn. The trilobites discovered by Dr. Pringle at Callander belong to the American genus *Pagetia*, which is unknown elsewhere in Europe; Shimer and Shrock give its distribution as " S. Appalachians and Cordilleran region; Australia ". Here, then, we have an American faunal element on the south-eastern side of the Highlands, and thus the Dalradian country cannot be regarded as a land-barrier separating American and Anglo-Welsh Cambrian provinces. Instead it would seem that we should look in the region of the Irish Sea, (Anglesey, the Lake District, the Southern Uplands), where Cambrian, except for the disputed Bray Series, is unknown in the sense of pre-Tremadoc, and may well be non-existent. The Ingletonian—if indeed pre-Cambrian—may be a part of such a barrier, and even if Ordovician

must, like the Watch Hill Grits, point to the existence of ancient crystalline rocks near by.

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8th November, 1947.

QUERY AS TO THE TEMPO OF AUSTRALIAN DENUDATION

SIR,—The conclusions of various workers in eastern Australian States indicate the survival there of extensive relics of very ancient land surfaces which have been continuously subject to denudation throughout several geological periods.

Andrews,[1] who has found very extensive residuals of peneplains forming a high plateau and a somewhat lower benchland in the New England district of New South Wales, has attributed the highest well-preserved peneplain (itself surmounted by some monadnocks) to a cycle interrupted in the Cretaceous period.

Basaltic lava flows of Oligocene or early Miocene age survive extensively in the New England district, and Voisey [2] has found that they bury a land surface of rather strong relief. The high altitude at which the residuals of the lava now stand is, therefore, in part original : they have been high enough above base-level to be subject to erosion for several geological periods, and yet they have escaped destruction.

Craft [3] recognizes a Triassic surface of almost perfect peneplanation (never since buried) in the Blue Mountains, and this, with flanking benchlands, makes a composite surface in southern New South Wales which was, he claims, in existence with a configuration very much like that of the present day (though then somewhat lower as a whole) prior to the outpouring over parts of it of Middle Tertiary basalts.

In Victoria according to Hills [4] the most ancient land surface survives in some plateau residuals on areas of particularly resistant rocks that have been at a fairly high altitude ever since the interruption by upheaval of a Cretaceous cycle of erosion. A later and lower-standing peneplain, extensively but imperfectly developed at the expense of the dwindling Cretaceous surface, was buried, together with monadnocks rising above it, under Oligocene basalts, and the compound mass has

[1] E. C. Andrews, The Geology of the New England Plateau, Part 1 : Physiography. *Rec. Geol. Surv. N.S.W.*, 7 (4), pp. 281–300, 1904.

[2] A. H. Voisey, The Tertiary Land Surface in Southern New England, *Jour. and Proc. Roy. Soc. N.S.W.*, 76, pp. 82–5, 1942.

[3] F. A. Craft, The Surface History of Monaro, N.S.W., and The Coastal Tablelands and Streams of N.S.W., *Proc. Linn. Soc. N.S.W.*, 58, pp. 229-244 and 437–460, 1933.

[4] E. S. Hills, Some Fundamental Concepts in Victorian Physiography, *Proc. Roy. Soc. Vic.*, 47, pp. 158–174, 1934.

been subject to erosion ever since. Subsequently to this (in the Pliocene period) the differential upheavals took place which gave the more prominent mountain masses of Victoria, such as the Eastern and Central Highlands, their present relief and their initial form. Though subject since that date to continuous erosion, they have suffered only a moderate reduction in bulk.

So in New South Wales and Victoria the earth movements that initiated erosion over much of the region are to be regarded as ancient, and the tempo of denudation has been rather slow. This is borne out by the calcareous nature of the exiguous Tertiary marine sediments. Such a state of affairs may be contrasted with some of Teichert's recent findings in Western Australia.[1] In the North-west Basin of Western Australia this author finds anticlines and domes " in various parts of the basin ". Besides younger formations a very thick succession of Permian marine strata is extensively bevelled by erosion, and the terrain is also intensely faulted (p. 135). All the deformation took place in the Pliocene period, however. " The young age of the deformation is evident," he writes. " There is at present no clear evidence for more than one tectonic phase, and this is not older than Pliocene, since Miocene limestones, possibly even Pliocene, have been folded. The youthfulness of the structures is a factor that must be regarded as favourable to the accumulation and preservation of oil " (p. 136).

Yet the surface has since undergone an " almost perfect planation " (p. 135), and it had, indeed, been already planed even before the end of the Pliocene period, for the " almost continuous laterite layer " over the peneplain of Western Australia is regarded by Teichert as most likely a Pliocene formation (p. 119). From such findings one must conclude that the tempo of denudation in Western Australia has been unbelievably rapid. Judging from figures given by the author, if the geological history of the larger Desert Basin, where folded Permian strata are reported, can be assumed to be similar to that of the North-west Basin, the bulk of clastic sediments that resulted from this vast postulated Pliocene denudation might it seems, as a guess, approach 100,000 cubic miles, all of which must, of course, be now below sea-level in the Indian Ocean. This is obviously possible, but it is a large order : it would raise the level of the ocean by nearly four feet.

In the account Teichert gives of the late geological history of Western Australia under the head " Summary of Tertiary Palaeogeography " there is no hint of the occurrence of a Pliocene orogeny, or, indeed, of any differential movements whatever of that date. In writing this section the author has obviously overlooked the implications of the

[1] C. Teichert, Stratigraphy of Western Australia, *Jour. and Proc. Roy. Soc. N.S.W.*, 80, pp. 81–142, 1947.

presence of the folded Miocene and Pliocene strata mentioned on p. 136. It seems necessary to assume also that the Pliocene date assigned (admittedly on negative evidence) to the folding of the thick mass of Permian strata is a still more serious error, the vast implications of which the author has failed to see.

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10th November, 1947.

TECTONIC HISTORY OF THE MALVERNS

SIR,—Dr. F. M. Trotter, in a private communication, has taken me to task for omitting any reference to the Forest of Dean or Mayhill in my recent note on the tectonics of the Malverns (*Geol. Mag.*, lxxxiv, 1947, p. 233). While this was partly intentional, I was certainly unaware at that time of the 1942 Survey Memoir on the Forest of Dean, apparently owing to an erroneous assumption that a revised 1 inch to the mile map usually precedes, or at any rate accompanies, a memoir. I should therefore like to remedy the omission.

Dr. Trotter points out that strong intra-Carboniferous movements during the post-Lower Carboniferous/pre-Upper Coal Measure time interval are proved by the attitude of the Crease Limestone (the basal member of the old Upper Limestone division of the Lower Carboniferous). This limestone, the chief repository of the haematite ores, has been worked to a depth of 800 to 1,000 feet for a distance of 5 to 6 miles on the eastern side of the coalfield, and its dip to this depth over the whole zone of working is within 20 degrees on either side of the vertical. The limestone is overlapped with great unconformity by the Upper Coal Measures.

Dr. Trotter also refers to the fact that between the south end of Mayhill and the Mitcheldean area the whole thickness of the Old Red Sandstone, together with the Carboniferous Limestone, dips westwards between 60 degrees and the vertical. It seems difficult to avoid the conclusion that the Mayhill structure, and the several N.S. structures in Lower Carboniferous rocks which protrude from beneath the Upper Coal Measures of the Forest of Dean coal basin, were formed by the same pre-Upper Coal Measure movements which produced the overturning in the Malverns.

Although these movements appear to have started in Lower Carboniferous times, and to have continued in places during post-Upper Coal Measure times (as shown by the westerly dip of between 20 and 40 degrees on the eastern side of the Forest of Dean), the evidence seems to suggest that the most violent episode, followed by great

erosional activity, took place before the Upper Coal Measures were deposited.

North of the Forest of Dean, on the Malvern Line, there appears to be no evidence that the Upper Coal Measures were at all seriously affected by the northward drive of the Variscan orogenesis (i.e. the culminating episode in the south of the post-Carboniferous/pre-Permo-Triassic movements). In the Forest of Dean, however, Dr. Trotter draws attention to the Staple Edge monocline (N.N.E.-S.S.W.) in which the Upper Coal Measures have been proved underground to plunge steeply westwards for 700 feet vertically (see Fig. 9 of the Forest of Dean Memoir), and also to the Ridge anticline (N.N.W.-S.S.E.). another pronounced feature proved underground in Upper Coal Measures. These structures at any rate may have been induced by the Variscan orogenesis. They are, however, relatively minor features, being 3 miles and 1½ miles in length respectively. It is to be expected that structures of Variscan age should play an increasing part in the picture as the Variscan front is approached, and their trends would be expected to follow various directions, which would be resultants of a relative movement to the north on an established N.-S., N.W.-S.E., or N.E.-S.W. grain.

Messrs. Moore and Trueman, in discussing the structure of the Bristol coalfield (*Proc. Geol. Assoc.*, 1939) have hinted that it might be possible to find an adequate explanation for the several puzzling Lower Carboniferous Limestone masses in the east of the area (Wick, Vobster, etc.) by assuming an early movement from the east. If this could be proved it would introduce a satisfying clarity into the tectonic picture of the southern part of the Malvern Line.

With reference to the Malvern fault, the interesting evidence given by Dr. Morley Davies in his recent letter (*ante* p. 320) can be used in favour of a fault or unconformity. In my experience it is most unusual for relics of a downfaulted formation to adhere to a fault plane in the way he describes, but somewhat less unusual in the case of an unconformity. However, even accepting the evidence as in favour of minor faulting at that point, I do not see why it should follow that other faults should lie to the east. Was the Keuper necessarily co-extensive with the Bunter wind-blown sand ?

N. L. FALCON.

WOKING,
SURREY.
15th November, 1947.

REVIEWS

THE MINERAL RESOURCES OF TANGANYIKA TERRITORY. By Sir E. O. TEALE and F. OATES. pp. 167, with 2 maps. Published by the Crown Agents for the Colonies, 1946. Price 15*s*.

In the preface to this Bulletin, Sir Edmund Teale pays a tribute to the memory of the joint author, Frank Oates, to whom much of the work of its compilation is due, and who unfortunately died just before his retirement after many years of faithful service to the Geological Survey of Tanganyika.

Before passing on to the main subject of this publication, the mineral resources and geology of the Territory, I wish to pick a quarrel with the stratigraphical table on page 2 of the cover. The stratigraphical systems recognized are here classified as Archaean, Palaeozoic, Mesozoic, and Kainozoic : the first includes the Basement Complex, Lower and Upper and the Muva-Ankole System, while the Bukoba and Karroo Systems are classed as Palaeozoic. Now there is no evidence to show that the Bukoba System is Palaeozoic, as it is unfossiliferous, and where the Karroo System is fully developed, in the Union of South Africa, much of it is certainly Triassic, and therefore Mesozoic. There are in the Union an embarrassing number of sedimentary systems with which the Muva-Ankole and Bukoba might be correlated. The whole point here is, as I have before emphasized, that in Gondwanaland the usual northern classification will not work.

The number of minerals actually found in Tanganyika is very large, but few are of economic value : in fact gold accounts for 86 per cent of the total value of the minerals actually worked. The rest includes diamonds, tin ore, salt, mica, silver, wolfram, lead ore, guano, red ochre, talc, and corundum.

In connection with the distribution of gold occurrences, some points of great interest relating to the granites of the country are discussed. It is emphasized that the granites can be divided into two types ; migmatitic and truly magmatic, definitely intruded as liquid, and it is only in association with the latter, here regarded as Younger Granites, that payable gold deposits are found.

The diamonds are either found in, or are obviously derived from, kimberlite pipes or other intrusions believed to be of Cretaceous age, like those further south. Tin and wolfram deposits are of less importance than in Uganda, although of the same type. Mica occurs widely in pegmatites in the Lower Basement Complex, and seems likely to become of increasing importance, as reserves of material of good quality appear to be very large in many fairly easily accessible localities. There are also great quantities of salt connected with the drying up

of lakes, as is well known. Unfortunately in some places there is a great deal of carbonate with the chloride.

Altogether this Bulletin contains a lot of interesting information, and it is accompanied by a good coloured geological map of the territory, and also by a map showing all known mineral occurrences.

R. H. R.

THE GEOLOGY OF THE COUNTRY AROUND WITNEY. By L. RICHARDSON, W. J. ARKELL, and H. G. DINES. Explanation of Sheet 236, pp. xi + 150, with viii plates and 6 text-figures. *Mem. Geol. Survey*, 1946. Price 5*s*.

This memoir is the Explanation of the 1 in. sheet No. 236. It covers an area west of the city of Oxford, which just comes into its eastern margin. In point of fact it overlaps very considerably with the special Oxford Sheet (1908, 2nd edition, 1926). The formations at the surface range from Lower Lias to Gault, but within this sequence there are two very important gaps, namely from Upper Lias very nearly to the base of the Great Oolite, and between Kimmeridge Clay and Lower Greensand (although some divisions missing in the latter do occur not far from Oxford). The great break between Jurassic and Cretaceous in the southern Midlands is, or should be, well known by this time, but it may perhaps be doubted whether the importance of the post-Liassic break in some places is quite so generally recognized. In this area the Yeovilian, Aalenian, and nearly all the Bajocian zones are absent, and in places there is precious little Middle or Upper Lias. There is thus a striking change from the Cotswolds, which are not far away : in fact the north-west corner of this map is sometimes reckoned as part of the Cotswolds. There is not very much in the way of Glacial deposits (perhaps 20 feet), but a great development of gravel terraces near Oxford, which figure largely in modern Pleistocene geology.

Nearly half the map is occupied by the Oxford clay and possible Kellaways beds. It is no doubt significant that the description of what must be the type area of the Oxford Clay is polished off in two and a half pages. The meaning of this is, of course, scarcity of exposures. There is nothing like the Peterborough brick-pits, and perhaps mercifully so, as it would be hard to find anything in geology quite so depressing. On the other hand in the limestone facies there are an amazing number of quarries in the Middle Jurassic : all the well-known Oxford building stones (some of which were disasters), including also the very limited range of the true Stonesfield Slates.

There was once a little working of Middle Lias iron ore at Fawler but the well-known modern iron-mining field near Banbury does not extend into this sheet. Included in the chapter on Economic Geology

is a note on soils and agriculture by Mr. C. G. T. Morison of the School of Rural Economy, Oxford.

OXFORD STONE. By W. J. ARKELL. pp. 185, with 37 plates and 26 text-figures and a folding map. London: Faber and Faber, 1947. Price 25*s*.

The subject of this book is dealt with from almost every possible point of view: geological, historical, architectural, aesthetic, and practical. A hundred years ago Oxford was notorious for the dilapidated condition of many of its important buildings. An interesting point here brought out is that many of the earliest buildings are still in a wonderfully good state of preservation. It is chiefly among the renaissance and later buildings that the great disasters occurred, largely owing to the use of stone unsuited to the newer styles of architecture.

Practically all the building stones of Oxford are Jurassic and nearly all from the Middle and Upper Jurassic, but even Portland stone is scarce. One vivid impression produced by reading this book is that nearly all the important buildings of the later ages have had to be more or less rebuilt, refaced, or patched, often with quite unsuitable material. Now obviously many stones do not stand the local conditions well. It is a curious and perhaps rather unexpected fact that the two old University towns are particularly smoky places, owing to the enormous numbers of domestic fires in the Colleges and lodging houses. Since nearly all, one might almost say all, the Oxford stones are limestones, the effect of the sulphur in the smoke is obvious. Both Oxford and Cambridge are also very damp in winter, which makes matters worse. Unfortunately, the Headington stone, which was so much used in Oxford, stands this sort of thing very badly, and even the famous Bath stone but indifferently. The Clipsham stone from Rutland is found to give the best results as to wear and has been extensively used in more modern times for refacing and patching, in the latter case sometimes with unfortunately spotty results. It has been found specially good for replacing pinnacles, of which there appear to be far too many in Oxford.

Dr. Arkell is, on the whole, very restrained on the subject of the many architectural nightmares of the Gothic revival to be found in both the old Universities. On this subject the Master of Trinity has recently written " The monstrosities of architecture erected by order of the Dons of Oxford and Cambridge in [the middle of the nineteenth century] give daily pain to posterity ", and he might have added " and daily discomfort to those who have to live and work in them ".

The geological treatment of the sources of the stones, as would

naturally be expected, is very complete and well illustrated by small maps, while the concluding chapters on the working of the quarries and the methods of dressing the stone and on the advantages of keeping buildings clean by washing afford very interesting reading. It is admitted that in respect of cleaning Cambridge is ahead of Oxford. Dr. Arkell is, on the whole, rather in favour of a reasonable amount of creepers on college buildings. In this matter, from personal experience the present writer dissents strongly—on the ground of sparrows, earwigs, woodlice, and the labour involved in sweeping the fallen leaves.

R. H. R.

MEDIEVAL CASTLES IN NORTH WALES. By E. NEAVERSON. pp. 54 with 22 figures. Liverpool University Press and Hodder and Stoughton, 1947. Price 6*s*.

This is not a guide book : neither is the treatment primarily historical or archaeological. It is, as set out in the sub-title, a study of the geological factors that have controlled the building of these castles ; choice of sites, water supply, and building stones. The castles are divided into four categories. First, castle mounds without buildings—these date mostly from the Norman invasion of Wales, when the actual buildings were of wood and of course have long since disappeared. Secondly, the Early English stone castles, likewise arising from invasions of Wales during the twelfth century. Thirdly, the Welsh stone castles, obviously in the main defensive. And lastly the great stone castles such as Conway and Caernarvon, built by Edward I after he had adopted a plan of penetration by sea from a base at Chester.

Although Chester is not in Wales a description is given of its natural features which have been much modified by the silting up of the Dee. It is of interest to reflect that Chester was once an important seaport, the predecessor of Liverpool, and up to comparatively recent times it was the usual port of embarkation for Ireland. The remarkable natural strong-point of Beeston Castle is also described.

One chapter contains a general account of the geology of North Wales and throughout most attention is paid to the nature and source of the stones employed, as well as to the physiographical, that is geological, reasons for the choice of sites. In many cases water supply seems to have been a difficulty ; although, as the author points out, medieval castles did not need very much water, still they needed some for drinking, although the consumption for washing was but small.

The book is pleasantly written and very readable. It is illustrated by 22 figures, of which 10 are charming plates, with two photographs on each.

THE FORMATION OF THE CONTINENTS BY CONVECTION. By G. F. S. HILLS. pp. 102, with 5 figures. London : Edward Arnold and Co., 1947. Price 7*s*. 6*d*.

The object of this book is to discuss some of those problems of geology for which no solution has yet been found. The list is fairly long. The author begins on the first page by posing the question why the continents are all in one hemisphere, and why they cover only one quarter of the earth's surface. He might well have gone a step further back and asked why there are any continents at all. His solution is as follows : starting with a liquid earth, just beginning to crystallize, heavy minerals (mainly olivine) sink and light minerals (mainly felspar) float. Then, in his own words :—

> As the result of organized convection, floating felspar crystals would be carried by the magma surface currents to the two poles, where they would be entangled with the liquid magma.

This poleward flow is attributed to lower temperature at the poles, but it may be doubted whether, when the earth was liquid, there would be a significant difference of temperature between the equator and the poles. Again, quoting the exact words, we are told :—

> Later, when the magma became too viscous for further separation of crystals by gravity and convection flow practically ceased, the two floating continents would float in the magma towards the equator, where gravity is least, and adjoin.

Thus we arrive at Laurasia and Gondwanaland, which come to lie on either side of Tethys. These continents are 15 km. thick and being mainly granite are highly radioactive, but the lowest layer is uncrystallized and below this again comes a weak plastic basaltic layer, which is presumably the same as Daly's vitreous basalt. Later in the book this plastic layer is made to play many parts.

It would be impossible within any reasonable compass to discuss here all the topics dealt with in this book, but the foregoing has been given in some detail, as the theory there propounded is the basis of the treatment of most of the other subjects, such as isostasy, folded mountain chains, a flow of basalt over the floor of the western Pacific, the origin of the Atlantic, the roots of mountains, fjords, the Quaternary Ice Age, and so on. Much use is naturally made of seismological data and of radioactivity. One chapter is devoted to the salt in the sea and another to the absence of calcareous fossils before Cambrian times. Altogether the book affords much food for thought for those interested in some of the unsolved problems of geology. There seems to be a deliberate avoidance of continental drift. This was perhaps wise, as most of the discussions of it have concentrated on mathematics, and have paid little attention to purely geological facts which appear to be inexplicable in any other way. The impossibilities do not all work in one direction.

R. H. R.

GLACIAL GEOLOGY AND THE PLEISTOCENE EPOCH. By R. F. FLINT. Yale University—New York: John Wiley & Sons. London: Chapman & Hall, 1947, 589 pp. Price 36*s*.

Professor Flint is well known as an expert on glacial geology. In this work we have a critical review of the problems and stratigraphy of this complex subject.

The whole approach is refreshingly critical and scientific, difficulties are left as difficulties needing further work, but his clear statement of the evidence and justifiable deductions therefrom will be welcomed by students and teachers alike.

The first chapters give an excellent summary of the present views on glacial processes followed by details of the various kinds of glacial deposits, the loess and outwash materials. The importance of weathering as a basis for determining the age of drifts is emphasized.

A very useful summary of the history of such terms as Quaternary and Pleistocene is given and certain definitions are suggested although it is stated that " the present attempt is an effort to formulate a scheme that will be workable until such a time as the matter is taken up by a fully-qualified group ". In this connection it may be noted that the boundary between the Pleistocene and Pliocene is one of the topics for discussion at the forthcoming International Geological Congress and it is hoped that a resolution will be passed asking the Congress to give its blessing to this or some similar scheme which will thereby have an authoritative basis.

The accounts of the glacial stratigraphy, first of North America, then Europe and finally the rest of the world will be found to be most useful. It is natural that in a book published in America the glacial succession of Britain only finds a minor place but Professor Flint endeavours to build up a composite standard succession from the East Anglian drifts. He concludes that " even in the most favourable region authorities are not universally agreed on a standard sequence " ; in these words he certainly does not overstate the present unsatisfactory position. America seems luckier than England in having reached more agreement on a standard succession at any rate as far as the Central United States is concerned.

Pleistocene chronology is dealt with in detail in chapter 18 and the causes of climatic fluctuations in chapter 22. In general Professor Flint is impressed by the objections to the Heat-distribution hypothesis in its various forms and even goes so far as to state " it is difficult to escape from the inference that supposed coincidences between the [Milankovitch] curve and the facts of Pleistocene stratigraphy have obscured, in the minds of proponents of the scheme, the doubtful factors that lie back of the curve itself ".

As a working hypothesis Professor Flint prefers what he terms the Solar-Topographic hypothesis which is in general a combination of something rather near Sir George Simpson's hypothesis combined with the presence of highlands as the prime factor in determining the growth of ice sheets.

Most chapters end with a summary and conclusions which add considerably to the value of the book for quick reference. Certainly we must be grateful to Professor Flint for giving us so good a book.

W. B. R. K.

GEOLOGY AND MINERAL DEPOSITS OF THE LITTLE BAY AREA. By H. J. MACLEAN. pp. 45, with 6 plates. Bulletin No. 22, Geological Survey of Newfoundland, St. John's, 1947.

This bulletin describes the geology and ore deposits of an area on the north-east side of Newfoundland where in the second half of last century a good deal of copper-mining was carried on. It is an area of fjord-like topography, with no great elevation and deeply dissected, having been heavily glaciated, probably in the Wisconsin phase, with subsequent re-elevation and raised beaches.

The rocks are very largely volcanic, about half the surface being occupied by basalt flows, with some intrusives. The volcanics and some accompanying sediments are considered, on rather slight evidence, to include Ordovician and Silurian, with a strong unconformity between them, attributed to Taconic tectonic movements.

The ore-bodies appear to belong to a very common type, namely, lenticles of sulphides in sheer zones, with pyrite, marcasite, chalcopyrite, and pyrrhotite, with some sphalerite, wurtzite and occasionally a little gold.

R. H. R.

GEOLOGICAL MAGAZINE

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The Lower Ordovician Cryptolithids of the Llandeilo District

By ALWYN WILLIAMS

(PLATE VI)

INTRODUCTION

THE following description of new genera and species of Lower Ordovician Cryptolithids is the result of a stratigraphical and palaeontological investigation of the rocks in the Llangadock-Llandeilo district, Carmarthenshire.

Two stocks have been investigated, namely the Lloydolithid stock and the Marrolithid stock. In both, the thoraces and the pygidia appear to be constant throughout, but an investigation of the cephala and especially the pitted borders has yielded results recorded below. In the study of the latter the writer has worked along lines laid down by Bancroft (1929) and later verified by Whittington (1940, 1941) and Lamont (1935, 1941), with whose opinions on the taxonomic value of pit relationship the author wholeheartedly agrees.

Finally, the writer believes, and has here attempted to show, that these Cryptolithids have a definite zonal value, and accordingly the conclusions deal largely with this point of view.

ACKNOWLEDGMENTS

I wish to express my indebtedness to the late Professor H. P. Lewis of U.C.W., Aberystwyth, for being an unfailing source of encouragement and guidance in both the stratigraphical and palaeontological work. My thanks go, too, to Dr. C. J. Stubblefield, who gave me considerable advice in the earlier stages of the work and allowed me access to relevant material in the Survey Museum, and who later read the manuscript and made many valuable comments thereon; to Professor O. T. Jones for helpful discussions on the various attendant stratigraphical problems; to Mr. J. C. Challinor for suggestions in the early stages of the work; and to Mr. A. G. Brighton for allowing me access to specimens in the Sedgwick Museum.

The work has been undertaken during the tenure of a D.S.I.R. grant and a University of Wales Fellowship, and to these bodies I express my grateful thanks.

Sub-family CRYPTOLITHINAE Bancroft 1933 emended Whittington 1941

Lloydolithus (Protolloydolithus) sub-genus nov.

Definition.—A new sub-genus erected to include species of a primitive Lloydolithid stock with one row of pits external to the girder.

Lloydolithus (*Protolloydolithus*) *ramsayi* (Hicks) (Text-fig. 1)

1875. *Trinucleus ramsayi* Hicks *Q.J.G.S.*, p. 183, pl. x, figs. 1, 2.
1912. *Dionide atra* Reed (*pars*, *non* Salter), *Geol. Mag.*, xlix, p. 202.
1940. *Trigrypos atra* Kobayashi (*pars*, *non* Salter), *Jap. Journ. Geol. Geog.*, xvii, p. 204.

Dimensions.

Syntypes, G.S.M. 25401	New material (almost entire), G.S.M. 75228	
cephalon (distorted)	cephalon .	length, 0·7 cm.
length . 1·0 cm.		width, 1·65 cm.
width . 1·7 cm.	thorax .	length, 0·3 cm.
		width, 1·4 cm.
A16717 (Sedgwick Museum)	pygidium .	length, 0·3 cm.
Fragment of border and cheek.		width, 1·2 cm. (est.)

Revised Description based on Syntypes and New Material.—The border of the cephalon is in outline gently convex anteriorly ; almost straight laterally ; sloping slightly forwards posteriorly.

A single row of pits (E_1), which are well defined, are separated from the interior rows by a girder. Of the interior pits, I_1 are well developed and are distributed on the incline of the girder. In the anterior region of the head shield there are some six to eight pits in rows below I_1 which tend to have a radial arrangement. Laterally and posteriorly, due to frequent intercalation of pits, the radial arrangement is masked, so that generally the pits are irregularly disposed.

Glabella, moderately convex, broad, tapering posteriorly. Anteriorly it lies well back from the " pit margin " leaving a semi-oval area depressed below the level of the glabella. There is a median tubercle on the glabella and posteriorly two pairs of glabella furrows groove the glabella, with a pair of occipital furrows lying immediately behind.

Cheeks are parabolic in outline, moderately swollen. The axial

furrows are not deeply defined and flex outwards to separate off two triangular areas (alae) posteriorly.

The cheeks and semi-oval area have a reticulate and nervated ornament, the latter, on the cheeks, branching out from a central point on the axial furrow.

The thorax consists of six segments, as in all Trinucleids.

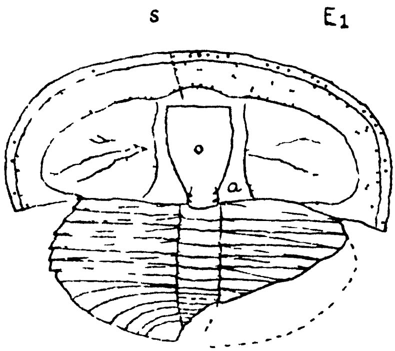
The pygidium (incomplete) is semi-circular in outline, depressed

The axis, acutely triangular, tapers posteriorly and is composed of at least 12 segments (seen on complete pygidia collected from the same locality) which are fused towards the apex. Laterally eight pleurae are visible, bending sharply posteriorly at their extremities.

Type Horizon.—Lower Llanvirn.

Locality for the New Material.—500 yards E.N.E. of Cwm Breinant farm (1,500 yards E. of Llandeilo town).

Discussion.—The author has been permitted to examine the syntypes of *T. ramsayi* Hicks, one at present in the Geological Survey Museum



TEXT-FIG. 1.—*Lloydolithus (Protolloydolithus) ramsayi* (Hicks) (GSM. 75228), an almost complete individual, s semi-oval area, a : alae (×3).

(G.S.M. 25401) featuring a distorted cephalon, and the other consisting of a fragment of the border and cheek in the Sedgwick Museum (A16717) ; and is of the opinion that they are conspecific with the material collected from the Breinant area (G.S.M. 75228). In both syntypes the external row of pits, the irregularly disposed internal rows, and the nervated and reticulate cheeks can be seen. In syntype G.S.M. 25401 the glabella, alae, etc., correspond in every respect to the Breinant material.

Reed, in his paper (1912) on *Dionide atra* Salter, considered *T. ramsayi* to be conspecific with *D. atra* and therefore dropped the designation *T. ramsayi* in favour of the earlier founded *Dionide atra* The synonymy of the two has been reiterated by Kobayashi (1940)

who made *D. atra* the genotype for the new genus *Trigrypos* within the Dionideidae. Reed was led to believe in the synonymy of *D. atra* and *T. ramsayi* by the collection of cephala and associated pygidia from the Upper Llanvirn at Scolton. He identified the pygidia as being conspecific with a pygidium from Ty Obry named *D. atra* by Salter (1866, pl. 10, fig. 2), and considered the cephala, thus named, to be identical with *T. ramsayi.*

The Scolton material (see Reed, 1912, figs. 2 to 4*a*), together with the pygidium featured by Salter, has been examined at the Sedgwick Museum and the following differences have been seen to exist between *D. atra* and the *T. ramsayi* syntypes.

(1) In *D. atra* the border is surrounded by a series of large tubercles (in A16713*a* they seem to form one row but in A16715*a* there is evidence of more than one). They are quite distinct from the external row of pits and girder of *T. ramsayi.*

(2) In *T. ramsayi* the border is pitted along irregularly radial lines (in syntype A16717 strong cleavage has given the border a veined appearance though occasional pits can still be made out). In *D. atra* the whole border is veined in a reticulate fashion and no pits were observed.

(3) The cheeks of *T. ramsayi* are coarsely reticulate and nervate, those of *D. atra* are smooth.

(4) There is no trans-genal furrow in *T. ramsayi*, and, finally, the pygidia are fundamentally different.

P. ramsayi is related to *Lloydolithus* (including *L. lloydi* and *L. corndensis* (Salter, 1853, pl. 7). It compares with the latter genus in general shape, development of alae, disposition of the glabella, and character of the pygidium, but differs from *Lloydolithus* in the irregular development of pits, the reticulate and nervate ornament, the median tubercle, the absence of pseudo-antennary pits, and the less swollen aspect of the glabella and cheeks and the development of E_1 only.

Since *P. ramsayi* occurs earlier than *Lloydolithus* it is assumed that it forms the primitive stock whence was derived *Lloydolithus.*

Whittington (1941) has placed *Lloydolithus* provisionally in the Cryptolithinae, but expressed doubt because *Lloydolithus* has two rows of pits external to the girder. The presence of E_1 only in the new sub-genus confirms the inclusion of the Lloydolithids in the above-mentioned sub-family.

Notations and Terms Used in the Description of Marrolithids

In the study of *Marrolithus* (sensu lato) the author has paid special attention to the border which is ornamented by a series of pits

arranged in 46 to 50 radial rows. In all Marrolithids the outermost pit (E_1) in each row is separated from the internal pits (I_1) by a well-defined girder. Owing to the sharp angulation of the border the rows are distributed so that 30 to 34 are aligned along the anterior part of the border and 7 to 9 along the lateral parts of the border, on either side.[1]

Since the author attaches importance to the number of internal pits developed along each row a notation is used to describe the numerical content of each row counting from the median line of the cephalon. The prefix A is used to indicate the anterior border. $A6I^5$ indicates that the sixth row out from the median line consists of five internal pits (see Text-fig. 2*a*).

It has been found that the pits increase in size along the radial axis and also from the median line towards the angulation, thus the smallest pits are those in front of the glabella, and the largest are those within the antero-lateral angle. When pits are very large they are contained within six tubercles each tubercle marking one corner of a hexagon. These tubercles find their equivalent in the development of complementary pits in the lower lamella. The tubercles are probably due to a pinching up of the sides, with over development of pits, and their presence has been used as diagnostic of the later forms of *Marrolithus* (sensu stricto).

Both corners of the border of *Marrolithus* (sensu stricto) have been affected by a varying degree of inflation which is probably related to over development of pits and has resulted in variable areas of both the upper and lower lamellae being distended in a dorsal and ventral direction respectively. It has been found that the degree and extent of inflation becomes progressively greater in the more advanced forms of *Marrolithus* (sensu stricto). In order to describe precisely the area in which inflated pits occur a notation is used to describe its lateral and anterior extent. The prefix CL indicates lateral and CA indicates anterior extent; for the purposes of counting, the row of pits which correspond to the actual corner of the border is counted with the anterior extension (see Text-figs. 2*b* and 4). Thus, the extent of inflation in Text-fig. 2*b* is $CA9I^1$, $CA7I^2$, and $CA4I^3$, that is, the concentric row I^1 shows nine pits, I^2 seven pits, and I^3 four pits, which are inflated along the anterior part of the border.

It may be noted that it has proved convenient in practice to apply the notation only to those pits occupying the crest of the inflated

[1] The constancy of pit distributions is shown by the fact that although over 1,500 cephala have been examined, only one specimen has proved freakish in pit distribution ; a cephalon collected from the Transition zone between the Lower and Middle Llandeilo, which has a pit intercalated externa to the girder at the border angle to form E_2 in line with $A16I_6$.

area. Pits which occur on the incline of the inflated area are disregarded, though they may be, in some instances, as large as the ones counted.

Marrolithus Bancroft 1929

Genotype.—Trinucleus ornatus var *favus* Salter 1848.

1848. *Trinucleus ornatus* var. *favus*, Salter, *Palaeont. Appendix Geol. Mem. Gt. Brit.*, 2, pt. 1, p. 350, fig. 3.
1929. *Marrolithus favus*, Bancroft, *Mem. Manch. Lit. Phil. Soc.*, 75, p. 77.
1938. *Marrolithus favus*, Stubblefield, *Geol. Surv. Gt. Brit., Summ. Prog.*, 1936, pt. 2, p. 36.
1941. *Marrolithus favus*, Whittington, *Journ. of Palaeont.*, 15, no. 1, p. 24.

Investigation has shown that the term *Marrolithus favus* has been used to include forms which can be referred to three distinct subgenera In the elucidation and definition of these subgenera the main difficulty is the recognition of the original *T. ornatus* var. *favus*. Salter's diagrammatic figure was stated by him to be from a Penblewin specimen (Salter, 1848, p. 36), and the forms to occur in several parts of the Llandeilo flags of S. Wales. As Dr. Stubblefield has already pointed out (1938, p. 36), Penblewin is situated on Bala rocks, and although the specimens probably come from Llandeilo flags situated between a quarter and half a mile south of the village, reference to type locality is vague ; further, there are discrepancies between the supposed figured specimens and the type diagram. Specimens preserved in the Geological Survey Museum, known to have been studied by Salter, include two distinct species ; these comprise three specimens from Penblewin and one specimen from Glandwr (both localities in Carmarthenshire). The three specimens from Penblewin consist of two casts of upper lamellae and a glabella with a fragment of the anterior border preserved (Geol. Surv. Mus. 24588, 24590, and 24589 respectively). The Glandwr specimen is a preservation of practically the entire cephalon (Geol. Surv. Mus. 35672). In his original description of *T. ornatus* var. *favus* though Salter referred to the Penblewin specimens, the published drawing is probably based on the Glandwr specimen.

The author has been permitted to examine, at the Geological Survey Museum, C. R. Bone's original drawings made for Salter's 1848 publication. The early drawing of *T. favus* was that of a diagrammatized glabella and genae, with an upper lamella comparable to the Penblewin specimens. The second execution and the one that was published was that of the same diagrammatized glabella and genae but with

the upper lamella comparable to the Glandwr specimen. It is possible, therefore, that Salter first recognized the *favus* type from the Penblewin specimens, but that subsequently he became aware of the far better cephalon from Glandwr which became the model for Bone's published diagram. His note in the original description that all varieties exist between *T. ornatus* and *T. ornatus* var. *favus* would tend to substantiate this and would also explain the tendency to generalization in the drawing.

In addition to Penblewin Salter lists Penllwynon, Gwenllwyn, and Dynevor (just west of Llandeilo town) as localities of *T. ornatus favus* (1848, p. 240). The author has surveyed the Dynevor area and has found that the entire range of Llandeilo rocks are exposed there at some locality or another. However, the Old Quarry at Dynevor, N.E. of the mansion, a classic hunting ground for Llandeilo fossils and a collecting locality used by the early surveyors, has yielded Marrolithids which are, in the opinion of the author, conspecific with those from Penblewin. It is therefore proposed to consider the Penblewin specimens as the types for *Marrolithus favus* and to use material collected from the Old Quarry at Dynevor in compiling an emended description.

The Subgenera of Marrolithus

During the recent survey the Marrolithids (sensu lato) have been found to fall into three natural groups ; the difference, in the opinion of the author, having a subgeneric value as follows :—

Sub-family Cryptolithinae Bancroft, emended Whittington, 1941. Genus, *Marrolithus*, Bancroft, 1929, emend. nov.

Cryptolithids having a clavate glabella with only one row of pits external to the girder, and with a sharply angulated border.

Marrolithus sensu stricto.

Marrolithids with a varying area of inflated pits developed at the border angle.

Marrolithoides, subgen. nov.

Marrolithids in which the pits are uninflated differentially (except occasionally and then only in gerontic stages) and have a simple radial arrangement more pronounced than in *Marrolithus* (sensu stricto).

Telaeomarrolithus, subgen. nov.

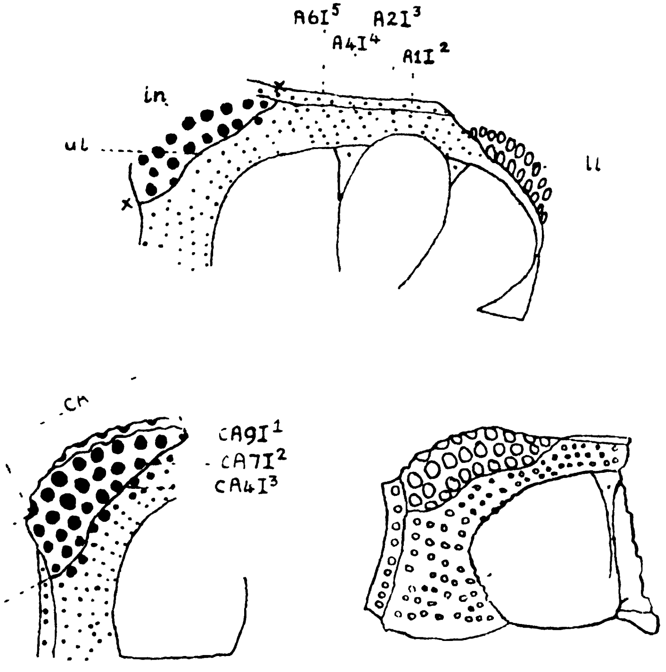
Marrolithids with no inflated pits, but with the whole border fimbriated. Glabella tending to develop a pseudo-frontal lobe.

Marrolithus (sensu stricto)

1. *Marrolithus favus* (Salter) (Text-figs. 2*a–c*, Pl. VI, fig. 9)

Dimensions.

Syntypes	New material (cephala)	
G.S.M. 24588—upper lamella.	G.S.M. 75211	G.S.M. 75212*a*
G.S.M. 24590—upper lamella.	Length, 0·9 cm.	0·9 cm.
G.S.M. 24589—glabella and fragment of anterior border.	Width, 2·0 cm.	2·4 cm. (est.)
	G.S.M. 75213 Portion of border.	



TEXT-FIG. 2*a*.—*Marrolithus favus* (Salter) (GSM. 75211) a cephalon showing the anterior arrangement of pits. The boundary of the inflated pits (in) is represented by the continuous line (xx), ll : lower lamella, ul : upper lamella ($\times$ 3).

TEXT-FIG. 2*b*.—*Marrolithus favus* (GSM. 75213) part of the border showing the notation used in the description of the inflated pits ($\times$ 3).

TEXT-FIG. 2*c*.—*Marrolithus favus* (GSM. 75212*a*) a portion of the lower lamella and a cheek ($\times$ 3).

The outline of the border anteriorly is slightly convex, markedly so towards the angulation, so that the angulation is coincident with or anterior to the line of the anterior face of the glabella ; laterally straight.

External pits in a single row, girder well marked, 16 on each side anteriorly, nine laterally.

Internal Pits.—Anterior arrangement: $A1I^2$, $A2I^3$, $A4I^4$ $A6I^5$ laterally I_7 incipient. Area of inflated pits: Up to I_3 in depth, very much swollen. Extent: $CA9I^1$, $CA7I^2$, $CA4I^3$, $CL3I^1$, $CL2I^2$, $CL1I^3$. Near the angulation the pits are oval and are very large, each surrounded by six small tubercles which are revealed as pits in the lower lamella.

Cheeks swollen, parabolic in outline. One pair of pseudo-antennary pits behind an anterior lip situated on each side of the anterior face of the glabella. Axial furrows deep, Glabella clavate, carinate, the axial furrow boundaries steep, practically vertical. One pair of glabella pits are present, occipital ring obscure, genal spine strong.

Type Horizon.—Upper Llandeilo flags.

Locality for New Material.—Old Quarry, 300 yards N. of Dynevor mansion, one mile W. of Llandeilo town.

Discussion.—Distinct from other species of the subgenus in the extreme maturity of pits (in other species the pits are smaller, and the tubercles incipient or undeveloped), in the strongly convex antero-lateral border, in the far greater area occupied by inflated pits and in the swollen aspect of cheeks and glabella. Anterior pit arrangement, too, is more mature with I_4 and I_5 developed nearer the median line.

2. *Marrolithus favus* var. *moderatus*, var. nov. (Text-fig. 3, Pl. VI, fig. 8)

Dimensions.

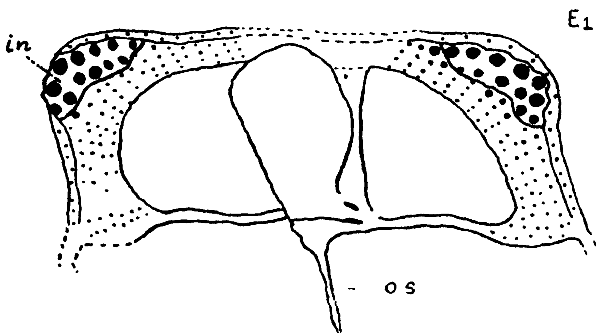
Holotype (G.S.M. 75214)	Paratype 1 (G.S.M. 75215)	Paratype 2 (G.S.M. 75216)
Cephalon (compressed).	Cephalon.	External impression
Length . 1·0 cm.	Length 0·9 cm.	of part of upper
Width . 1·7 cm.	Width . 2·0 cm.	lamel.
	Occipital spine.	
	Length 0·65 cm.	

In outline the border is similar to that of *M. favus*, strongly convex at the anterior corners, straight laterally, and sloping back to the cheeks posteriorly.

Pits are large, progressively so to the area of inflated pits where they are mature and are surrounded by a hexagon of tubercles. Girder is well marked, E_1 generally below the level of I_2 pits. Anterior pattern: $A1I^1$, $A2I^2$, $A5I^3$, $A12I^5$, incipient I_6 at the corners. In holotype and paratype 1 there are only 28 rows of pits anteriorly and eight rows laterally, and these figures are representative of mature

individuals, but gerontic specimens (e.g. paratype 2) may develop up to 36 rows anteriorly. Area of inflated pits has the following extent : $CA5I^1$, $CA4I^2$, $CL2I^1$, and $CL1I^2$ (in paratype 2 the formula reads : $CA7I^1$, $CA4I^2$, $CA2I^3$).

Cheeks swollen, parabolic in outline. A pair of pseudo-antennary pits is developed, one on either side of the anterior face of the glabella, and each contained anteriorly by a small lip. Glabella clavate, moderately carinate, separated from the cheeks by a pair of steep



TEXT-FIG. 3.—*Marrolithus favus* var. *moderatus* nov. (GSM. 75215), a cephalon, in : inflated pits, os : occipital spine (× 3).

axial furrows. A pair of glabella pits is present and the occipital ring is continued posteriorly as a long slender spine.

Type Horizon.—Upper Llandeilo flags.

Type Locality.—Outcrops in stream 150 yards N.W. of Troed-y-rhiw farm, two-thirds of a mile S.S.E. of Ffairfach.

Discussion.—The new variety is related to *M. favus* by its maturity of pits, and in its strongly convex antero-lateral border, but is distinct in its smaller extent of inflated pits and fewer rows of pits.

3. *Marrolithus inflatus* sp. nov. (Text-fig. 4, Pl. VI, fig. 3) [1]

Dimensions.

Holotype (G.S.M. 75217)			Paratype (G.S.M. 75218)		
Cephalon—	Length	0·8 cm.	Cephalon—	Length	0·7 cm.
	Width	2·1 cm. (est.)		Width	2·1 cm.

The border outline is gently convex anteriorly, slightly concave

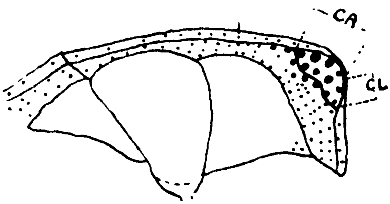
[1] This species is here described along with two varieties, one of which precedes the species itself in time and although the term variety is usually employed in Palaeontology for contemporary forms in this case for the sake of description the author has departed from that practice

laterally, and sloping outwards posteriorly (the border outline of paratype is straight anteriorly due to distortion.)

Pits small, with an incipient or no development of tubercles. Thirty rows occur along the anterior part of the border and eight laterally. Interior pits: notation for paratype is $A2I^3$, $A10I^4$, $A13I^5$. I_6 is developed in the holotype antero-laterally. Inflated pits form a scalene triangle about the border angle extending as follows: $CA4I^1$, $CA3I^2$, $CL2I^1$, $CL1I^2$.

Cheeks are quadrate in outline, moderately swollen, one pair of pseudo-antennary pits are present, the anterior lip to each is not well defined.

Glabella is clavate, swollen, projecting forwards over the border. One pair of glabella pits occur just anterior to a pair of occipital



TEXT-FIG. 4.—*Marrolithus inflatus* nov. (GSM. 75217), a cephalon showing the notation used in the description of the inflated pits (× 3).

grooves. The occipital ring is narrow projecting posteriorly to form an upturned occipital spine.

Type Horizon.—Lower Llandeilo flags.

Type Locality.—20 yards S.E. of Careg-y-foel-gam farm, 2 miles S.S.E. of Llangadock.

Discussion.—Distinct from *M. favus* in the gently convex anterior border the smaller pits, the absence of tubercles, and in the smaller area of differential inflation which generally affects only four pits anteriorly and is never more than I_2 in depth.

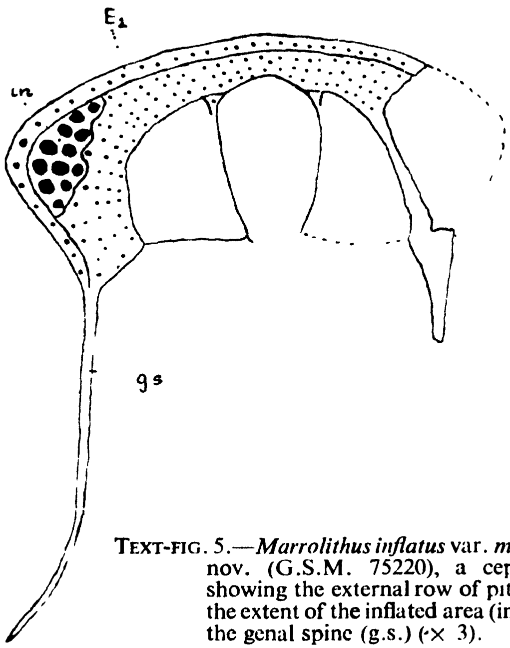
4. *Marrolithus inflatus* var. *maturus* var. nov. (Text-fig. 5, Pl. VI, fig. 4)

Dimensions.

Holotype (G.S.M. 75220)		Paratype (G.S.M. 75221)	
Cephalon—Length	. 0·8 cm.	Cephalon of younger specimen than holotype.	
Width	. 2·0 cm.	Length	. 0·6 cm.
		Width	. 1·6 cm. (est.)

The border outline is convex anteriorly, slightly concave laterally, and sloping outwards posteriorly. Genal spines are long (1·4 cm.) and curved outwards.

Pits.—Thirty radial rows occur anteriorly and six(?) laterally (in the vast majority of cephala collected from the type locality and elsewhere the pattern is 30 rows anteriorly and eight laterally). Interior pit arrangement: The notation for the paratype is $A1I^2$, $A2I^3$, $A6I^1$,



TEXT-FIG. 5.—*Marrolithus inflatus* var. *maturus* nov. (G.S.M. 75220), a cephalon showing the external row of pits (E_1), the extent of the inflated area (in), and the genal spine (g.s.) (×3).

with I_6 developed laterally. The inflated pits occupy a lozenge shaped area, I_3 in depth. The anterior extent reads $CA5I^2$, $CA3I^2$, $CA1I^3$, lateral extent $CL2I^1$, $CL1I^2$.

Cheeks are quadrate, moderately swollen. Glabella is clavate. Pseudo-antennary pits, glabella furrows, etc., as in *M. inflatus*.

Type Horizon.—Lower Llandeilo flags.

Type Locality.—Quarry 100 yards N. of Ty-gwyn farm, half a mile E. of Llandeilo.

Discussion.—An advanced form of *M. inflatus*, from which it is distinguished by the greater area of inflated pits, and by the greater number of internal pits developed along the radial rows anteriorly.

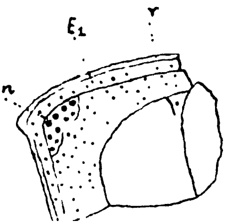
It is noteworthy that in the strata immediately succeeding the beds containing *M. inflatus* var. *maturus* occur degenerate forms of the latter (G.S.M. 75222) with very little inflation affecting the pits, which compare closely with some of the "Trinucleids" described by Oehlert (1895).

5. *Marrolithus inflatus* var. *incipiens*, var. nov. (Text-fig. 6, Pl. VI, fig. 2)

Dimensions.

Holotype (G.S.M. 75223)	Paratype 1 (G.S.M. 75224)	Paratype 2 (G.S.M. 75225)
Cephalon— Length 0·5 cm. Width 1·35 cm. (est.)	Portion of border.	Cheek and portion of border.

Border outline anteriorly straight, curved back at the corners, laterally straight, posteriorly sloping back.



TEXT-FIG. 6.—*Marrolithus inflatus* var. *incipiens* nov. (GSM. 75223), a reconstructed cephalon, r : thickened rim, in : inflated area (× 3).

Pits.—Small, no tubercles are found. An extremely thickened rim up to 0·5 mm. thick bounds E_1. Interior pit arrangement : Anteriorly obscure, but I_3 is seen opposite the pseudo-antennary pits, probably equivalent to $A3I^3$, and assuming this, the formula would read $A7I^4$, $A11I^5$, with I_6, at the border angles, developed incipiently. Pits are only slightly inflated to form a gentle elevation with the following extent : $CA4I^1$, $CA3I^2$, $CL2I^2$, and $CL1I^2$.

Cheeks are small, semi-oval, moderately swollen ; pseudo-antennary pits as in *M. inflatus*. The glabella is not well preserved but the alignment of the glabella furrows show that it tapers slowly posteriorly, sharply elevated.

Type horizon.—Upper Llanvirn to basal Llandeilo flags.

Type Localities.—100 yards S. of level crossing in the railway cutting, Ffairfach ; and (for paratypes) outcrops 420 yards N.N.E. of the Lodge, 1½ miles S.S.W. of Llangadock.

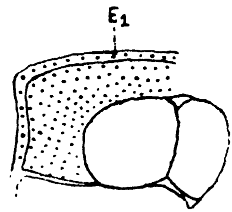
Discussion.—A precursor of *M. inflatus* from which it differs in its much smaller size, the extreme thickening of the rim to give a pronounced band round the border, the smaller pits, and the shape of the border.

6. *Marrolithus primus*, sp. nov. (Text-fig. 7, Pl. VI, fig. 1)

Holotype (G.S.M. 75226)		Paratype (G.S.M. 75227)	
External impression of half a cephalon.		Cephalon of young individual.	
Length	0·65 cm.	Length	0·5 cm.
Width	1·8 cm. (est.)	Width	1·5 cm. (est.)

Border outline angulate, anteriorly slightly convex; laterally straight, and posteriorly straight.

Pits.—Small, primitive, without tubercles. E_1 is only well defined laterally where the border curls down. The holotype is incomplete but it is estimated that there are about 32 rows of pits anteriorly and eight laterally. Interior pits arranged as follows: I_3 opposite the pseudo-antennary pit and therefore probably equivalent to $A3I^3$, $A8I^4$, $A10I^5$, with $A16I^7$ at the corner. There is no differential inflation, only a suggestion of turgidity, and though few fragments of the lower lamella are preserved, it is probable that the border is only slightly bi-convex. Cheeks are semi-oval, moderately swollen; a pair of pseudo-antennary pits occur with a slightly swollen triangular area anterior to each.



TEXT-FIG. 7.—*Marrolithus primus* sp. nov. (GSM. 75226), a part of a cephalon, there are no inflated pits in this species (×3).

Glabella is clavate, sharply elevated, tapering posteriorly, and is surmounted by a median tubercle. A pair of glabella furrows indent the glabella just anterior to a pair of well-marked occipital grooves defining the occipital ring which is prolonged into an occipital spine.

Type Horizon.—Basal beds of the Upper Llanvirn.

Type Locality.—Quarry 1 mile W. of Golden Grove mansion, Llandeilo.

Discussion.—*M. primus* is included in *Marrolithus* (sensu stricto) group despite the absence of differential inflation, in which characteristic it is distinct from all other species of *Marrolithus*. The suggestion of turgidity merits its inclusion in this subgenus as does the fact that the border is very sharply angulated so that the outline of the border is not approximately parallel to the glabella-genae outline as in *Marrolithoides*.

Marrolithoides subgen. nov.

Marrolithids in which the pits are uninflated differentially (except occasionally and then only in gerontic stages) and have a simple pit

arrangement more pronounced than in *Marrolithus* (sensu stricto). Genotype *M. simplex* sp. nov.

1. *Marrolithoides simplex* sp. nov. (Text-fig. 8, Pl. VI, fig. 5)

Dimensions.

	Holotype (G.S.M. 75206)	Paratype 1 (G.S.M. 75207)	Paratype 2 (G.S.M. 75208)
Cephalon—			
Length . .	0·7 cm.	0·6 cm.	0·5 cm.
Width . .	1·5 cm.	1·3 cm.	1·2 cm.
Thorax—			
Length . .			0·3 cm.
Width . .			1·0 cm.
Pygidium—			
Length . .			0·2 cm.
Width . .			0·9 cm.
Genal spine—			
Length . .			0·85 cm.

Border outline anteriorly gently convex; laterally straight; posteriorly sloping outwards. The border angles are behind the level of the anterior glabella edge. The E_1 row of pits is elevated. There are 36 rows of pits along the anterior part of the border and eight laterally. Interior pit arrangement is as follows: $A1I^1$, $A2I^2$, $A10I^3$, with I_4 developed at the angulation. There is no inflation of the interior pits. Genal spines long, practically straight.

Cheeks are lunate to quadrate in outline, moderately swollen; the glabella is clavate, and moderately swollen with a centrally placed tubercle on the dorsal face. A pair of pseudo-antennary pits are developed, one on each side of the anterior face of the glabella. The occipital furrows are shallow and straight, the occipital ring slightly elevated, and produced posteriorly to form an occipital spine.

Thorax is composed of six segments. The pygidium is semi-oval with at least five pleurae distinguishable, bending back distally. Axis of the pygidium is broad, pointed, with at least six segments.

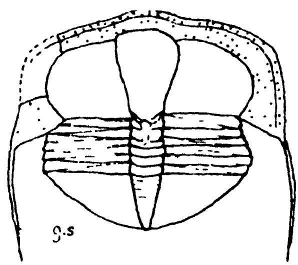
Type Horizon.—Middle Llandeilo flags.

Type Locality.—Quarry, 300 yards W. of Wernellyn farm, 1 mile S.S.E. of Llangadock.

Discussion.—*M. simplex* constitutes the type species of *Marrolithoides* and is probably the stock whence were derived the new variety *M. simplex* var. *elevata*, and the new species *M. anomalis*, from which it differs in characteristics discussed in the descriptions of the two latter.

Dr. Stubblefield has drawn my attention to the fact that the type of *Trinucleus gibbifrons* McCoy came from Golden Grove Llandeilo. The type, however, was reported lost by Woods (1891, p. 52) and has not been found since, so that texts and figures have to be relied upon to assess the relationship between this species and the Marrolithids described here.

McCoy first described *T. gibbifrons* in 1849 (pp. 411–12) and incorporated a modified account in the palaeontological section of *Palaeozoic Rocks and Fossils* (Sedgwick and McCoy, 1854, p. 145, pl. 1E, figs. 14, 14*a*). The figures represent a cephalon with the pits of the border (three rows anteriorly, four rows laterally, including the external row) arranged as they are in *Marrolithoides simplex* (sp. nov.), but the glabella is far more gibbous anteriorly. Both descriptions, however, contradict the figure and each other in pit distribution. In 1849 (p. 411) he wrote that there are "five rows in front of the cheeks" and in 1854, p. 145, "Three rows of punctures in front of the glabella and four rows in front of the cheeks more numerous at the sides." In both descriptions he emphasized the granulated nature of the cheeks and glabella, a rather significant statement since the granules are present in young specimens of *Marrolithus* (s.l.) but not in adult stages.



TEXT-FIG. 8.—*Marrolithoides simplex* sp. nov. (GSM. 75208), an immature individual showing the simple radial disposition of the pits and the long genal spines, g.s. (× 3).

There is also a considerable uncertainty about type locality. In 1849 (p. 412) the species was recorded as being common in the "Lower Silurian limestone of Golden Grove". In 1854 (p. 145) McCoy stated that the type came from the "Caradoc Sandstone of Golden Grove" and repeated that it was also "common in the limestone of Golden Grove, Llandeilo". The "Caradoc Sandstone" is almost certainly the Fairfach Grit which is fossiliferous at Golden Grove and is the type locality for *Marrolithus primus* (sp. nov.). The "limestone at Golden Grove" is Upper Lower Llandeilo which yields very few Marrolithids (s.l.) but is within the range of *M. simplex* (sp. nov.). I am, therefore, faced with the following alternatives :—

(1) *T. gibbifrons* is a young specimen of *M. simplex* (sp. nov.) but differing from the species in the very gibbous glabella and greater number of pits at the angles. Also the specimen could not possibly have come from the locality cited (1854, p. 145) if it were *M. simplex*.

(2) *T. gibbifrons* is a young specimen of *M. primus* (sp. nov.); against which conclusion are the less gibbous glabella, the angulated border,

and the greater number of pit rows antero-laterally of the latter species.

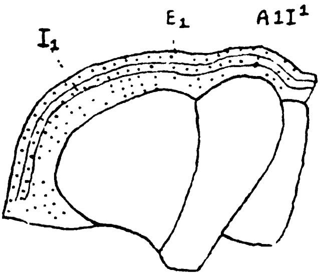
In view of the conflicting figures and description, and the uncertainty of locality, I cannot see my way to accept either of these hypotheses and I do not consider it possible to identify any of the species herein described as being conspecific with *T. gibbifrons*.

2. *Marrolithoides simplex* var. *elevata* var. nov. (Text-fig. 9, Pl. VI, fig. 7)

Dimensions.

Holotype (G.S.M. 75209*a*)	Paratype 1 (G.S.M. 75209*b*)	Paratype 2 (G.S.M. 75210)
Cephalon—	Part of cephalon.	Cephalon—
Length 1·1 cm.		Length 0·9 cm.
Width 2·0 cm. (est.)		Width 2·0 cm.

Border outline anteriorly convex, laterally straight, posteriorly straight ; the border angles are behind the level of the anterior face of the glabella. The rim of the border perforated by the external row of pits (E_1) is generally bent over. There are 34 rows of pits along the anterior part of the border, and eight rows laterally. The internal pits have the following disposition : $A1I^1$, $A2I^2$, $A6I^3$, $A10I^4$, with I_5 incipient antero-laterally. I_1 row of pits conspicuously elevated as a narrow concentric bar. The cheeks are moderately swollen. There is a pseudo-antennary pit with an anterior lip, one on each side of the glabella which is swollen and clavate in shape. The glabella is indented posteriorly by a pair of glabella pits and a pair of occipital grooves marking off an occipital ring which is upturned and produced backwards into a spine.



TEXT-FIG. 9.—*Marrolithoides simplex* var. *elevata* nov. (GSM. 75209*a*), a cephalon showing the elevation of one row (× 3).

Type Horizon.—Middle Llandeilo flags.

Type Locality.—Outcrops 100 yards N.W. of St. Tyfei's Church, one-third mile W. of Llandeilo town.

Discussion.—The elevation of the I_1 row, together with an intercalation of an extra row of pits antero-laterally, are not found in *M. simplex*, and it is upon these distinctions that the variety has been erected.

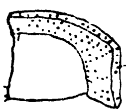
3. *Marrolithoides anomalis* sp. nov. (Text-figs. 10*a*, *b*, Pl. VI, fig. 6)

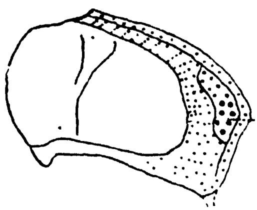
Dimensions.

Holotype (G.S.M. 75203)	Paratype 1 (G.S.M. 75205)	Paratype 2 (G.S.M. 75204)
Cephalon—	Cephalon—	Cephalon (*a*)—
Length 0·8 cm.	Length 0·7 cm.	Length 0·6 cm
Width 2·2 cm. (est.)	Width 1·4 cm.	Width 1·4 cm. (est.)
		Cephalon (*b*)—
		Length 0·8 cm.
		Width 1·7 cm.

Border outline convex anteriorly, almost straight laterally, sloping outwards posteriorly. The border angles lie behind the level of the anterior glabella face. There are 34 rows of pits along the anterior border and eight laterally.

Interior pit arrangement is obscure anteriorly but is probably (e.g. paratype 2*b*) $A3I^3$, $A8I^4$, $A15I^5$. I_6 developed at the angles





TEXT-FIG. 10*a*.—*Marrolithoides anomalis* sp. nov. (GSM. 75203), a cephalon of a gerontic individual showing the development of inflated pits (in) (×3).
TEXT-FIG. 10*b*.—*Marrolithoides anomalis* (GSM. 75204*b*), a young specimen showing the simple radial arrangement of pits (× 3).

with I_5 and I_6 each composed of two concentric pits. I_1 and I_2 are elevated at the angles above the level of E_1 and the interior pits. The extent of inflation is $CA6I^1$, $CA5I^2$, $CL2I^1$, $CL1I^2$.

Cheeks swollen, quadrate in outline ; axial furrows not pronounced. A pair of pseudo-antennary pits occur with a lip developed to the anterior of each.

Glabella swollen, clavate, carinate. The glabella furrows consist of a pair of oval pits anterior to a pair of occipital furrows. The occipital ring is narrow, slightly elevated, with a well-marked spine.

Paratypes 1 and 2*b* are young specimens which compare in all details with mature types, except that the pits are not inflated at the angles.

Type Horizon.—Middle Llandeilo flags.

Type Locality.—Quarry, 120 yards S.E. of Bridge House, 2 miles N.E. of Llandeilo town.

Discussion.—*Marrolithoides anomalis* is interesting in that gerontic individuals have inflated pits at the angles, comparable to *Marrolithus* sensu stricto, while young specimens are similar in pit arrangement to *Marrolithoides simplex.* Even mature and gerontic individuals with inflated pits, however, can be distinguished from *Marrolithus*, sensu stricto, by the fact that the angles are not as accentuated as in the latter (the border outline consequently is more nearly parallel to the outline of the glabella and genae than in *Marrolithus*) also the pits in *M. anomalis* are far smaller than in any Marrolithid sensu stricto. The author considers that the *Marrolithoides* arose from *Marrolithus*, sensu stricto, by a suppression of the inflated pits at the angles and by a general reduction in size and numbers of pits. The trend is not through *M. anomalis*, which is probably a freakish throw-back, because *M. anomalis* appears after the maxima of *M. simplex* in Middle Llandeilo times.

Telaeomarrolithus subgen. nov.

Erected to include Marrolithids with no inflation affecting the pits but with the whole border fimbriated. Glabella tending to develop a pseudo-frontal lobe.

Genotype—*Trinucleus radiatus* Murchison 1839

1. *Telaeomarrolithus radiatus* (Murchison) (Text-fig. 11, Pl. VI, fig. 10)

1839. *Trinucleus radiatus* Murchison, *The Silurian System*, p. 660, pl. 23, fig. 3.

Syntype 1 (G.S.C. 6838)	Syntype 2 (G.S.C. 6837)
Fragment of border with cheek.	Anterior and lateral portion of border.

Dimensions.

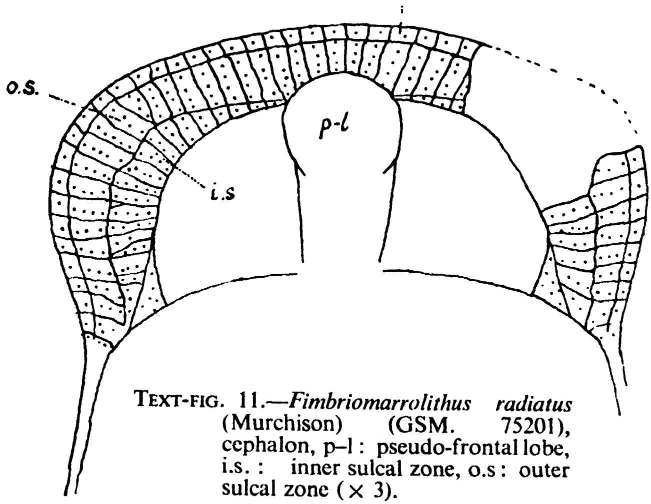
New Material 1 (G.S.M. 75201)		New Material 2 (G.S.M. 75202)	
Cephalon—		Lower lamella—	
Length	1·1 cm.	Length	0·9 cm.
Width	2·5 cm.	Width	2·5 cm. (est.)

Revised description based on new material.

Border outline almost straight anteriorly, with the angles somewhat rounded antero-laterally; straight laterally; sloping outwards posteriorly.

Pits are arranged in well-defined radiating sulci which are present along the entire border. Antero-laterally the sulcal ridges bifurcate

occasionally. The fringe of the border bearing E_1 row, which is strongly developed, is slightly upcurved. The interior pits are arranged in two distinct zones, an outer sulcal zone with the ridges well defined, and an inner sulcal zone, forming a triangular development antero-laterally, where the ridges are less well defined. The outer zone consists of 48 rows of pits, I_4 in depth, along the anterior part of the border with an intercalation of an extra row (I_5) at the border angles, whence



TEXT-FIG. 11.—*Fimbriomarrolithus radiatus* (Murchison) (GSM. 75201), cephalon, p-l : pseudo-frontal lobe, i.s. : inner sulcal zone, o.s : outer sulcal zone (× 3).

the number diminishes down to the genal spine (I_2). The inner zone starts just beyond the axial furrow. Here the pits are rather smaller in size than those of the outer zone, and are somewhat irregularly disposed so that the sulci are not so marked, with á maximum development of five pits along the rows that coincide with the angulation. (Here, therefore, the sequence is E_1, I_5 (in the outer zone), I_{10} (in the inner zone). Cheeks are almost triangular in outline with the base directed posteriorly, moderately convex. The glabella is poorly preserved in the new material, but an incipient development of a pseudo-frontal lobe is evident.

Horizon for the New Material.—Lower Dicranograptus shales (zone of *N. gracilis*).

Locality for the New Material.—Outcrops 200 yards S.S.E. of Crug, half a mile N.N.W. of Llandeilo town.

Discussion.—The two specimens, consisting of a fragment of the cheek and lateral portion of the border, are the figured syntypes upon which Murchison based his description of *T. radiatus*. During the

recent survey a number of specimens preserved in shales containing *N. gracilis* have been obtained from various localities in the Llandeilo area. The new material is, in the opinion of the writer, conspecific with *T. radiatus* agreeing in every respect of pit distribution, border angulation, fimbriation, etc., with Murchison's syntypes, and since it is better preserved, allows of a more complete description of the cephalic characters than in the original diagnosis (Murchison, 1839, p. 660).

It is the belief of the writer that most if not all of those specimens collected from the *N. gracilis* horizon throughout Carmarthenshire and Pembrokeshire and named *T. fimbriatus* are actually *T. radiatus* (specimens collected from the same locality as the new material have been named *T. fimbriatus* in the Geological Survey Memoir for the Ammanford district).

T. radiatus, it is true, bears a certain superficial resemblance to *T. fimbriatus* but differs from the latter in a number of fundamental characters, such as the number and arrangement of pits, the development of inner and outer sulcal zones, the angulation of the border, the shape of the cheeks, and the fact that the glabella does not have so marked a pseudo-frontal lobe.

It is these features that render *T. radiatus* distinct generically from *T. fimbriatus* and points to a derivation from a Marrolithid stock. In gerontic forms of *M. favus* there is a tendency for the glabella to broaden anteriorly, and it is noticeable that the anterior rows of interior pits tend to be separated by ridges. Moreover, a collapse of the inflated pits would give the outer sulcal zone so distinctive of *T. radiatus*, so that it would seem that this subgenus embraces the ultimate form of the Marrolithid stock.

CONCLUSIONS

(*a*) *The Marrolithids*.—The new subgenera and species of *Marrolithus*, sensu lato, described above have been found to characterize distinct stratigraphical horizons, and as such have been of considerable use in the zoning of the upper Llanvirn-Llandeilo sequence.

Marrolithus, sensu stricto, is considered to be the fundamental type whence the *Marrolithoides* and *Telaeomarrolithus* stocks have been derived.

The earliest described Marrolithid is *M. primus*, the prototype of this prolific genus, which is to be found in the lower beds of the upper Llanvirn. It is succeeded by *M. inflatus* var. *incipiens* which persists into the basement beds of the Llandeilo Flags. *M. inflatus* followed by *M. inflatus* var. *maturus* are limited to the lower Llandeilo and are considered to be index fossils of those times. The middle Llandeilo is characterized by species of *Marrolithoides*, which disappear as suddenly

as they appear, and are succeeded by *M. favus* and its variety which span the upper Llandeilo. Finally, *F. radiatus* is found in the shaly facies succeeding the Llandeilo Flags.

Telaeomarrolithus radiatus Murchison

Marrolithus favus Salter

Marrolithus favus var. *moderatus* var. nov.

Marrolithoides simplex var. *elevata* var. nov.

Marrolithoides anomalis sp. nov.

occasional specimens of intermediate forms

Marrolithoides simplex sp. nov.

Marrolithus inflatus var. *maturus* var. nov.

Marrolithus inflatus sp. nov.

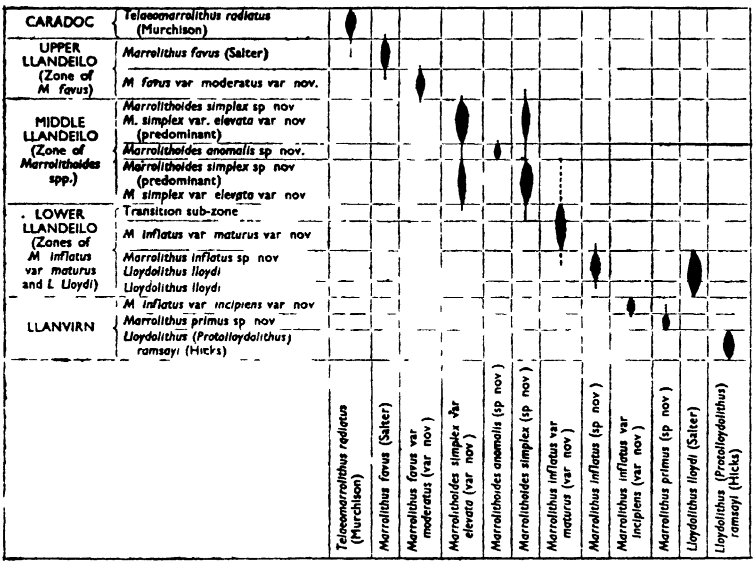
Marrolithus inflatus var. *incipiens* var. nov.

Marrolithus primus sp. nov.

The above sequence shows a progressive inflation of the pits at the border angles from *M. primus* up to *M. inflatus* var. *maturus.* This property of inflation is then suddenly lost, the pits revert to a simple radial arrangement, and the border becomes accordingly narrower to give *Marrolithoides.* That they evolved from the *Marrolithus sensu stricto* stock at about the stage of *M. inflatus* var. *maturus* is probable. The throw back *M. anomalis* demonstrates the *Marrolithus* affinity, and between the *M. inflatus* var. *maturus* zone and the zone of *Marrolithoides simplex* intervenes a thickness of rocks (termed the Transition zone) where occasional *M. simplex* are found associated with *M. inflatus* var. *maturus* and some curious degenerate forms of the latter. These degenerate forms are reminiscent in some instances of *M. primus* having only a general aspect of inflation, but the border is more nearly parallel to the glabella-genal outline as in *M. simplex*, and such forms may have given rise to the Marrolithoides stock.

The problem of the origin of *M. favus* is somewhat different. *M. favus* may have evolved suddenly from the *Marrolithoides* stock in a way analogous to the appearance of *M. anomalis*, but with the development of the border taken to its logical conclusion, becoming extremely tumid at the antero-lateral angles by virtue of an exaggerated inflation of the pits. The species probably arose, however, by more gradual mutational changes from *M. inflatus* var. *maturus* and as a background

to the overwhelming dominance of *Marrolithoides* during middle Llandeilo times, occur a few Marrolithids which tend to substantiate this opinion. For example, 15 feet below the rocks assigned to the *M. anomalis* zone in the type locality, two specimens have been found of *M. inflatus* var. *maturus* in an exaggerated form, and 1,670 feet above the base of the Llandeilo in the Cennan section, Ffairfach, a thin band of rocks have yielded some Marrolithids with a slightly



convex antero-lateral outline to the border, and inflated pits averaging $CA6{-}7I^{1}$, $CA5I^{2}$, and $CA2I^{3}$ in extent. These latter compare closely with *M. favus moderatus* but the pits are less inflated and the border outline is less convex antero-laterally in which characteristics the forms approach *M. inflatus maturus*.

It is conceivable, therefore, that *Marrolithus* species migrated elsewhere during Middle Llandeilo times where they evolved into forms (*M. favus*) that returned in force during Upper Llandeilo times.

The ultimate form *Telaeomarrolithus*, as stated above, is foreshadowed in some gerontic specimens of *M. favus* collected by the writer, and can be regarded as having been derived from this senile stock.

(*b*) *Lloydolithid stock.*—*Lloydolithus* (*Protolloydolithus*) *ramsayi* is characteristic of the *D. bifidus* shales in the Llandeilo district. It was the stock whence was derived *Lloydolithus lloydi*. *L. lloydi*, in the area surveyed, occupies a distinct horizon, appearing at the base of the

Llandeilo and disappearing suddenly at the top of the *M. inflatus* sub-zone ; for these beds it is used as an index fossil.

In the accompanying chart the writer has set out the stratigraphical distribution of the various species described above as they occur in the Lower Ordovician rocks of the Llandeilo-Llangadock area. The distribution has been plotted on stratigraphical divisions which represent the zonal sequences that have been used in mapping the area.

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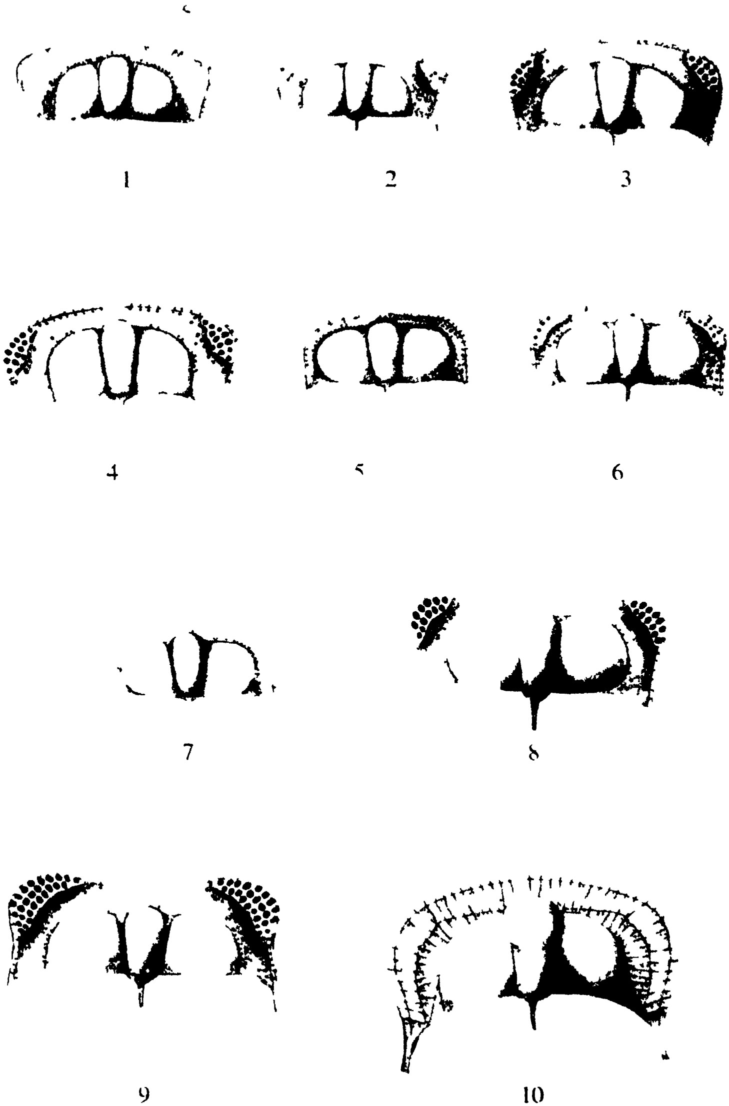
DESCRIPTION OF PLATE

The figures represent cephala of Marrolithus (sensu lato) arranged in stratigraphical order and reconstructed to show the various characters discussed in the text. All figures are enlarged to about 1½ times natural size.

FIG. 1.—*Marrolithus primus* sp. nov.
FIG. 2.—*Marrolithus inflatus* var *incipiens* var. nov.
FIG. 3.—*Marrolithus inflatus* sp. nov.
FIG. 4.—*Marrolithus inflatus* var. *maturus* var. nov.
FIG. 5.—*Marrolithoides simplex* sp. nov.
FIG. 6.—*Marrolithoides anomalis* sp. nov.
FIG. 7.—*Marrolithoides simplex* var. *elevata* var. nov
FIG. 8.—*Marrolithus favus* var. *moderatus* var. nov.
FIG. 9.—*Marrolithus favus* (Salter).
FIG. 10.—*Telaeomarrolithus radiatus* (Murchison).



Lower Ordovician Cryptolithids.

Stratigraphical Nomenclature of Scottish Metamorphic Rocks [1]

By J. G. C. ANDERSON

INTRODUCTION

AMONG the most controversial problems of British geology are those concerning the metamorphic rocks which make up the greater part of the Scottish Highlands. The writer, in common with many geologists whose work has brought them into contact with the region, has long felt that the discussion and solution of these problems would be greatly facilitated by a nomenclature less involved and more consistent than that at present in use. A simplified nomenclature, moreover, would do much to stimulate and hold the attention of students and general readers.

The weaknesses and inconsistencies of the present nomenclature are probably too well known to most workers, and particularly to those who have to teach this branch of geology, to require enumeration ; several will be mentioned in their appropriate place in the sequel. Some of the inconsistencies have sprung from the fact that there has been no general measure of agreement on the answers to many stratigraphical and tectonic problems. As regards stratigraphy, however, advances in the past twenty years or so, particularly by the use of current and graded bedding, have placed the successions in several important areas on a sound and generally accepted footing. Other inconsistencies, moreover, are not rooted in any geological problem but are due simply to variations in usage of the existing nomenclature by different geologists, or even by the same geologist at different times.

With these considerations in mind the writer, at the British Association Meeting in Dundee in September, 1947, put forward some suggestions regarding the stratigraphical nomenclature of the Scottish metamorphic rocks. The purpose of the present communication is to place these suggestions on record in a slightly amplified form.

NOMENCLATURE OF MAIN DIVISIONS

It is generally agreed that the Scottish metamorphic rocks can be grouped in three main divisions—the Lewisian, the Moinian, and the Dalradian. There is, however, no uniformity regarding the terms to which these words, generally used in an adjectival sense, should be linked. The nouns " System ", " Series," " Schists," and " Gneisses "

[1] The paper is published by permission of the Director, H.M. Geological Survey ; the views expressed are those of the author.

have all been widely used. None seems to be really suitable. The terms " Lewisian " and " Moine " (or Moinian) originally came into use more or less fortuitously through being applied, without the intention of founding a geological " System ", to the metamorphic rocks of particular districts. The term " Dalradian ", it is true, was specially coined, but in so doing Sir A. Geikie was at pains to point out that he was not creating a new " System ". The use of the term " System " in these connections has, therefore, no historical support. Moreover, if, as has been advocated, the Moinian consists of altered Torridonian strata and the Dalradian partially or wholly of altered Cambrian it is illogical to tabulate them in separate " Systems ".

Again, whatever their equivalence, each of the three main divisions surely accounts for a greater proportion of the geological time-scale than is represented by a Series in the fossiliferous portion of the stratigraphical table.

The objection to the use of such terms as " Gneisses ", " Schists," etc., lies in the implication that the division in question consists dominantly of rocks in this category. For instance, the Moinian rocks are largely granulites, not gneisses, and fully half of the Dalradian rocks are not schists in the accepted sense of the term. It is, of course, logical to speak of a particular gneiss as a Lewisian gneiss or a particular schist as a Dalradian schist, etc.

All that is known at present with fair certainty regarding the three main divisions is that each consists of an *assemblage* of metamorphic rocks, with many characteristics in common, representing a possibly continuous section of the geological column. The suggestion is therefore made that the Scottish metamorphic rocks should be divided, in the first instance, into the *Lewisian Metamorphic Assemblage*, the *Moinian Metamorphic Assemblage*, and the *Dalradian Metamorphic Assemblage*. Where there is no likelihood of confusion, or where there are frequent repetitions, the word metamorphic could be dropped and the terms Lewisian Assemblage, etc., used.

The proposed terms have the advantage of being stratigraphically and petrographically non-committal. Thus, should proof be forthcoming that the part or whole of one of the assemblages consists of rocks of a known age, it would still be appropriate to speak, for example, of altered Torridonian of the Moinian Metamorphic Assemblage.

Mention should, perhaps, at this stage be made of the Sub-Moine rocks which have been separated from those of the Moinian in the Morar district of Inverness-shire. As it is doubtful at the present stage of research whether these rocks belong to a separate formation or whether they merely form a basal group of the Moinian, they are conjecturally referred in Table I to a Sub-Moinian Metamorphic Assemblage placed between the Lewisian and Moinian Assemblages.

Table I
CLASSIFICATION OF SCOTTISH METAMORPHIC ROCKS

	NORTH-WEST HIGHLANDS	NORTHERN HIGHLANDS		GRAMPIAN HIGHLANDS
		MORAR	ROSS-SHIRE	
DALRADIAN METAMORPHIC ASSEMBLAGE	?= CAMBRIAN	—	—	for Groups see Table II
MOINIAN METAMORPHIC ASSEMBLAGE	?= TORRIDONIAN	— Upper Psammitic Group Striped and Pelitic Group Lower Psammitic Group	Upper Pelitic Group Upper Siliceous Group Lower Pelitic Group Lower Siliceous Group	=? Pelitic and Quartzitic Transition Group =? Central Highland Psammitic Group — —
Sub-Moinian Metamorphic Assemblage (incertae sedis)	—	Psammitic and Pelitic Schists, hornblende-schist etc.	—	—
LEWISIAN METAMORPHIC ASSEMBLAGE	Orthogneiss Group Paragneiss Group	— —	Orthogneiss Group Paragneiss Group	— —

Nomenclature of Subdivisions

In the past many workers, concerned for the most part with mapping particular areas, have designated the subdivisions they recognized by a locality prefix followed by a rock name, e.g. Ballachulish Limestone, Luss Slates, Appin Quartzite, etc. Now, natural and useful though this method may be in dealing with local sequences, it carries with it certain disadvantages. Firstly, by using such a term as the Ballachulish Limestone, for example, the writer often leaves a doubt in the reader's mind whether he is referring to a particular bed or beds of relatively pure limestone or to a considerable thickness of interbedded and varying strata of which limestone forms only a part. Secondly, consideration of structural problems affecting a wide district has been handicapped by this multiplicity of local names. It is an effort, to say the least of it, to recall that the Luss Slates are equivalent to the Aberfoyle Slates and these in turn to the Dunoon Phyllites, that the Ardrishaig Phyllites correspond to the Ben Lawers Schists, and so on. Terms of the type just quoted, too, are unsuitable, since in an area of regional metamorphism such as the Highlands the rocks of one stratigraphical unit may be in the state of slates in one district and mica-schists in another. Some authors, possibly to avoid the difficulties just outlined, have used either " Series " or " Group ". Of these, the present writer would, on the whole, prefer the non-committal term " Group ".

To define the Group many workers would prefer a locality name, e.g. Tayvallich Group. Unfortunately in most cases there is a number of locality names to choose from with very little guidance from the literature regarding priority. Furthermore, a geographical term has the disadvantage of conveying to the general reader nothing of the character of the Group. The proposal is, therefore, put forward that each Group should, in nearly every case, be defined by an adjective indicative of the dominant rock-type, e.g. Psammitic, Pelitic, Calcareous, etc. There is, of course, nothing new in such a method. A recent example of its application is provided by Richey and Kennedy in their naming of the Morar Succession.

There is naturally no reason why authors should not continue to use the old terms for purposes of local description with the general Group name added in brackets, e.g. Ben Eagach Black Schists (Carbonaceous Group).

Application of Nomenclature (Tables I and II)

(*a*) *To Lewisian Metamorphic Assemblage.*—As far as this assemblage is concerned it seems difficult, in the present state of our knowledge, to do more than recognize a Paragneiss and an Orthogneiss Group.

(*b*) *To Moinian Metamorphic Assemblage of the Northern Highlands.*—For the Moinian rocks of the Northern Highlands the stratigraphical nomenclature proposed for the Morar district should, in the writer's opinion, be used as widely as possible. It appears to be readily applicable to successions previously put forward for the rocks of the same age in Ross-shire.

(*c*) *To Moinian Metamorphic Assemblage of the Grampian Highlands.*—The Moinian age of the great series of granulites—often spoken of as the Central Highland Granulites—which make up the central part of the Grampian Highlands has long been accepted. These rocks may eventually be referred to the Upper Psammitic Group of the Northern Highlands. However, since it is impossible, until detailed mapping of districts along the Great Glen is completed, to make firm correlations across this major fracture, it is suggested that the granulites should in the meantime be referred to a Central Highland Psammitic Group. Besides the Central Highland Granulites, this Group should include such formations as the Struan and Eilde Flags.

The classification of strata immediately above the Central Highland Psammitic Group is confused by the difficult question of the relationship of the Moinian to the Dalradian. In several districts it seems clear, however, that the succession above the Psammitic Group consists of mica-schists, with a variable number of quartzites, followed by limestones. In Lochaber and Banffshire the mica-schists and quartzites (Table II) underlying the Ballachulish and Sandend Limestones respectively have previously been referred to the Dalradian. In the Spey and Findhorn valleys, on the other hand, mica-schists with subordinate quartzites succeeding the granulites have been regarded as Moinian.[1]

For the sake of uniformity the suggestion is therefore made that the base of the Dalradian should be drawn at the lowest limestone horizon, and that the variable series of underlying mica-schists and quartzites should be referred to a Pelitic and Quartzitic Transition Group, or more briefly a Transition Group, forming the top of the Moinian Metamorphic Assemblage.

(*d*) *To Dalradian Metamorphic Assemblage.*—The Dalradian Succession of Perthshire, originally set out by Sir A. Geikie in 1891, is now accepted in its essentials by nearly all Highland geologists. As shown (in a form slightly modified from the original) in Table II, col. 2, it has been used as a basis for the group names which, it is suggested (Table II, col. 1), should be applied to the major subdivisions of the Dalradian Assemblage as a whole. Comment is probably unnecessary

[1] Unpublished work by the author suggests that the Lochaber mica-schists continue north-eastwards by way of the Corrieyairack Pass to join up with the Findhorn mica-schists.

on the terms themselves which, it is hoped, are self-explanatory. A point, however, which perhaps requires emphasis (and which applies with equal force to the Moinian Groups) is that while the groups are named after the dominant rock types present they may include a substantial proportion of other types. In this connection, the inclusion of the Ben Lui Schists in the Lower Psammitic Group may seem a surprising departure. In the writer's experience, however, the Ben Lui Schists contain more quartz-schist, schistose grit, etc., than true pelitic schist. Moreover, the strata in districts other than Perthshire which are believed to belong to the Group are definitely mainly psammitic in character (Table II, cols. 3 and 4). As regards the formations placed in the Upper Pelitic and Calcareous Group and in the Upper Psammitic Group, effect is given to the view that the Aberfoyle Slates are stratigraphically equivalent to the Pitlochry Schists, and the Leny Grits to the Ben Ledi Grits.

In the remaining columns (3–6) in Table II the formations already recognized in certain districts other than Perthshire are tabulated opposite the general group to which the writer suggests they should be assigned. Some of the correlations put forward are doubtless open to criticism but they appear to the author the most likely to prove valid on the balance of the available evidence. They are based not only on a detailed study of the literature but also on personal observations in nearly the whole of the Grampian Highlands during the past fifteen years. It should be emphasized, too, that the local validity of the successions shown for the various districts has, in nearly every case, been verified by current and graded bedding.

Table II is intended as far as possible to be self-explanatory and it is not the purpose of the present communication to discuss the various issues involved. The following brief notes on the several districts may, however, be of assistance.

Cowal

If the proposed new nomenclature be accepted for Perthshire its extension to Cowal should entail no difficulty, as most outcrops are virtually continuous between the two districts.

Loch Awe and Islay

The lower part of Col. 4 (up to the Ardrishaig Phyllites) should not give rise to controversy, as the correlations with Perthshire are generally admitted. The classification of the formations listed in the upper part of the column, on the other hand, implies acceptance of a definite structural theory, namely, that the rocks above the Ardrishaig Phyllites, west of Loch Fyne, form the upper and un-inverted limb

of a great recumbent anticline (the Carrick Castle Fold), the lower (inverted) limb of which constitutes the Loch Tay Inversion Zone.

Ballachulish and Lochaber

Although correlation of the Ballachulish rocks with those of the rest of the Highlands has always been a matter for controversy it seems logical to place the Ballachulish Limestone, as the first calcareous horizon in the upward succession from the Moinian Assemblage, in the Dalradian Basal Calcareous Group. If such is the case it follows that the Appin Quartzite, etc., and the Cuil Bay Slates fall into the Quartzitic and Carbonaceous Groups respectively. The Appin " Limestone " or Dolomite offers some difficulty, and it is necessary to assume that it is a local development, possibly represented by the Dolomitic Group of Islay, but unknown elsewhere.

Banffshire and Northern Aberdeenshire

Correlations of the lower portion of the Banffshire Succession up to and including the Cowhythe " Gneiss " with the lower part of the Perthshire Succession are generally accepted. At the eastern margin of the Cowhythe " Gneiss " comes the discordance termed the Boyne Line. In compiling Table II the writer has adopted the view, supported by some workers but not by others, that the Boyne Limestone, which lies above the Boyne Line, corresponds to the Loch Tay Limestone and that the equivalents of the remaining Perthshire formations follow in upward sequence.

Conclusion

Some criticism may be aroused by the absence in the foregoing account of any mention of the numerous geologists who have worked on Highland problems and of any discussion of, or even reference to, the many important papers which have been published. Discussions of previous work would, if a balanced treatment were preserved, have inevitably led to a lengthy account of Highland problems which it was not the writer's purpose to produce. Moreover, up-to-date summaries of the present position in Highland research have just appeared in the second editions of the Regional Geologies of the Northern Highlands (Phemister, 1948) and the Grampian Highlands (Read and MacGregor, 1948). These works also contain full lists of references.

The writer's main purpose, in fact, has been to put forward a uniform scheme of stratigraphical classification for the Highland metamorphic rocks and to show how such a scheme might be applied in the light

of present knowledge. Criticism of the application of the scheme, in some aspects, is inevitable. It is hoped that such criticism will not weaken the case for the scheme in general, or at any rate, will not invalidate the author's contention that an improved nomenclature is desirable for a fuller understanding of Highland problems.

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Notes on Some Rugose Corals in the Gray Collection, from Girvan, Scotland

By H. C. WANG (Sedgwick Museum)

(PLATE VII)

SINCE the publication in 1880 of Nicholson and Etheridge's monograph of the Ordovician and Silurian fossils from Girvan, no further work has been done on the coral faunas of that region. While engaged on a revision of the rugose corals as a whole, I have studied a part of the Gray Collection in the British Museum (Nat. Hist.), of which the present article is an outcome. I am grateful to the keeper of the Department of Geology, and to Dr. H. D. Thomas for the loan of material and for the kind interest shown in my work, and to Dr. Stanley Smith for his valuable criticism and advice. This work was mainly carried out in the Sedgwick Museum, Cambridge, and I take the opportunity to express my thanks to Professor W. B. R. King and Mr. A. G. Brighton for facilities for study. Dr. H. D. Thomas and Dr. O. M. B. Bulman both kindly read the manuscript.

The following is a list of the species identified :—

D. Condystone Glen, Girvan.
 Dinophyllum sp.

C. Whitehouse Group, Ardmillan Series, Shalloch Hill, Girvan.
 Codonophyllum truncatum (Linn.).

B. Balclatchie Group, Barr Series, Balclatchie, Girvan.
 Pycnactis sp. cf. *crassiseptatum* (Smith).
 Streptelasma sp. cf. *corniculum* Hall.
 Palaeophyllum aggregatum Nicholson and Etheridge.

A. Stinchar Limestone Group, Barr Series, Craighead, Girvan.
 Streptelasma craigense McCoy.
 S. fossulatum sp. nov.
 S. rusticum (Billings).
 S. sp. cf. *corniculum* Hall.
 S. sp.
 Kiaerophyllum kiaeri Wedekind.
 K. europeum (Roemer).

Much has been written in recent years about the correlation of the Girvan succession. Comparatively little attention has been directed to the coral faunas, the evidence of which is, however, somewhat anomalous. In the Stinchar Limestone Group the leading species are *Streptelasma craigense*, *Kiaerophyllum kiaeri*, and *K. europeum*. The two former species occur abundantly in the bed *5a* of the Oslo region, Norway, and the latter is a common form in the Keisley Limestone.

Stretelasma rusticum is an American Richmond species. *Streptelasma* sp. cf. *corniculum* indicates some affinities to the American Middle and Upper Ordocivian *Streptelasma corniculum*, but the latter species may have a longer stratigraphical range than heretofore realized. The next horizon is the Balclatchie Group which contains *Palaeophyllum aggregatum*, so far only known from Girvan, and two other species comparable with *S. corniculum* and *Pycnactis crassiseptata*, the latter species being originally found in the Llandovery of Shropshire. It should be noted that *Streptelasma* species reminiscent of the *Pycnactis* group occur in late Ordovician times and must not be assigned too much weight in correlation. On the other hand, the corals in the Stinchar Limestone Group and the Balclatchie Group are distinct from each other, and only one doubtful species (*Streptelasma* sp. cf. *corniculum*) is common to both.

One species was found in each of the two upper horizons. *Dinophyllum* sp. from Condystone Glen is definitely a Middle Silurian form. The occurrence of *Codonophyllum truncatum* in the Whitehouse Group at Shalloch Hill is worth noting, as this species is so far only recorded from the Middle and Upper Silurian. My wider researches give evidence that *Streptelasma craigense* and *Palaeophyllum aggregatum* are probably ancestral to *Codonophyllum*, and that some Valentian forms from Shropshire described under *Streptelasma whittardi* by Smith (1930, pl. xxvii, fig. 14, pl. xxviii, figs. 1–8) possess well-defined septal trabeculae and are virtually members of *Codonophyllum*. Thus the presence of *C. truncatum* in the uppermost Ordovician or lowest Silurian is not so puzzling as it may seem at first sight.

Description of Species

ZOANTHARIA RUGOSA

Suborder *STREPTELASMACEA*

Family STREPTELASMIDAE

Solitary, rarely weakly compound corals, septa composed of fibre-fascicles grouped or not grouped into trabeculae, tabulae domed, dissepiments present in advanced forms.

Middle Ordovician—Middle Devonian.

Genus **Streptelasma** Hall 1847

Genotype.—*Streptelasma corniculum* Hall 1847, Middle Ordovician, U.S.A.

Diagnosis.—Trochoid or subcylindric corallum, narrow cardinal fossula, bilateral symmetry of septa apparent, major septa reaching axis and with denticulate inner edge, minor septa short, both composed of fibre-fascicles not clearly grouped into trabeculae, lamellar tissue

developed near the periphery, tabulae convex, no dissepiments. Middle Ordovician—Lower Devonian.

Remarks.—I have included in *Streptelasma* forms without well-defined trabeculae. It should be noted that *Streptelasma* represents an ancestral form through the diversification of which many coral stocks arise. Thus the grouping of the fibre-fascicles into stout trabeculae leads to *Codonophyllum* and *Schlotheimophyllum* ; the development of smooth trabeculae with dense fibre-fascicles and of peripheral lamellar tissue leads to the Dinophyllidae ; while the excessive dilatation of the fibre-fascicles in the interseptal loculi leads to the Pycnactidae. In *Streptelasma* proper are retained forms without well-defined trabeculae and without a conspicuous axial structure. Subcompound and fasciculate species form the subgenus *Palaeophyllum* ; large forms with complex axial structures constitute the subgenus *Kiaerophyllum* ; while species showing a shortening of the septa and a flattening of the tabulae are referred to the subgenus *Brachyelasma.*

Streptelasma craigense McCoy

Pl. VII, figs. 5–6, Text-fig. 1

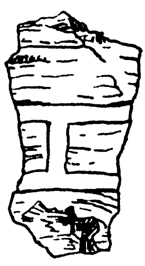
Streptelasma craigense, Nicholson and Etheridge, 1880, p. 74, pl. iv, figs. 4–4*c*.

S. saleboni Scheffen 1933, p. 5, pl. i, figs. 1–3.

Dybowskia radiata Scheffen 1933, p. 7, pl. i, fig. 4.

Material.—B.M. N.H. R.35110–4, 35115, 35118.

Diagnosis.—Ceratoid to subcylindrical *Streptelasma* with marked wrinkles on the surface, major septa nearly reaching the axis, axial structure weak, with a wide peripheral zone of contiguous septa, fibre-fascicles in the septa tending to form separate trabeculae.



TEXT-FIG. 1.—*Streptelasma craigense* McCoy. × 4/5. B.M. R35133.

Description.—This species is represented by many specimens, mostly cylindrical, but a few tapering slowly toward the proximal end. The average diameter is from 14 to 18 mm. There are 38–40 septa of each order, the major straight and thin, nearly reaching the axis, where a few loose trabeculae or denticles are present. A very prominent peripheral zone one-quarter as wide as the radius is formed by the contiguous ends of the major and the minor septa, subequal and averaging 0·5 mm. in thickness and separated from each other by zigzag interseptal sutures. The minor septa extend beyond the peripheral zone and have a length one-half that of the major. The

fibre-fascicles in the septa show a well-marked tendency to form trabeculae. Tabulae are mostly complete, flat in the wide central zone and steeply inclined toward the periphery. The prominent peripheral zone of contiguous septa and the grouping of fibre-fascicles into trabeculae recall very much the genus *Codonophyllum.*

Streptelasma rusticum (Billings)

Pl. VII, fig. 4

Streptelasma rusticum, Cox, 1937, pp. 11–12, pl. ii, figs. 11–13.

Material.—B.M. N.H. R.35127.

Diagnosis.—Large ceratoid to trochoid *Streptelasma,* major septa dilated and wavy, axial structure formed of isolated inner edges of septa, wide peripheral zone of contiguous septa beyond which the minor septa scarcely extend.

Description.—Corallum curved, trochoid, asymmetrical, larger diameter 19 mm. The major septa number forty, are dilated and wavy, nearly reaching the axis where they break up into separate segments. The peripheral zone shows stout fibre-fascicles and zigzag interseptal sutures as in *Streptelasma craigense,* but it is less than one-quarter the width of the radius. In the inner portion of the septa the fibre-fascicles are acutely pinnate and much dilated. The tabulae are incomplete and strongly arched, thus appearing as numerous inwardly arched plates in transverse section. In the abundance of isolated septal segments in the axial area and in the incomplete arched tabulae, this species approaches the subgenus *Kiaerophyllum.*

Streptelasma fossulatum sp. nov.

Pl. VII, figs. 7*a–c*

Holotype.—B.M. N.H. R.35124. Ordovician, Stinchar Limestone Group, Craighead, Girvan.

Diagnosis.—Small ceratoid *Streptelasma* with a prominent wide cardinal fossula, a few major septa, no minor septa, and without a marked peripheral zone of contiguous septal ends.

Description.—This species is represented by one curved ceratoid specimen about 11 mm. thick at the distal end and marked with septal grooves and wrinkles on the surface. Three successive transverse sections were cut which range from 4·5 to 10 mm. in diameter. A cardinal fossula is prominent in all three sections. In the lowest section there are eighteen major septa and the cardinal septum is well developed. The cardinal septum becomes almost lost in the upper two sections, where the total number of the septa increases to twenty-one. There is no marked septal dilatation at the periphery. Minor septa are as a rule absent ; some very short septa occur near the alar septa, but these may be newly inserted major septa. The fibre-fascicles in the

septa are acutely pinnate and are evidently not grouped into trabeculae.

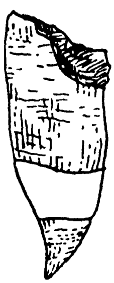
Remarks.—The thin wall and the apparent bilateral symmetry of septal disposition rather suggest affinities to *Petraia*, but in that genus the septa are composed of very fine and dense fibres and the wall is composed of lamellar tissue which partly invests the septa. The only species to which our form may be compared is the Valentian *Streptelasma praematurum* (Smith).[1]

Streptelasma sp. cf. *corniculum* Hall

Pl. VII, figs. 3*a*–*b*, Text-fig. 2

Material.—B.M. N.H. R.27214, 27220, 25129, 35119, 35131.

Description.—Several specimens both from the Stinchar Limestone Group and the Balclatchie Group are comparable with the genotype of *Streptelasma*. They are small, slightly curved cornute corals averaging 11 mm. in diameter, with deep calices. The cardinal and the two alar fossulae are usually recognizable and the septa are fairly dilated in the young stage. There is no conspicuous peripheral zone of contiguous septa and the minor septa are rudimentary. As a rule the major septa reach the axis and break up into a few isolated septal segments. The fibre-fascicles in the septa are long and acutely pinnate. There is the possibility that these may represent immature forms of *Streptelasma rusticum*.



TEXT-FIG. 2.—*Streptelasma* cf. *corniculum* Hall. × 1. B.M. R35129.

Subgenus **Palaeophyllum** Billings 1858

Genotype.—*Palaeophyllum rugosum* Billings 1858, Middle Ordovician, Canada.

Diagnosis.—Fasciculate *Streptelasma* with more or less well developed trabeculae in the septa.

Palaeophyllum aggregatum Nicholson and Etheridge 1880

Pl. VII, fig. 8, Text-fig. 3

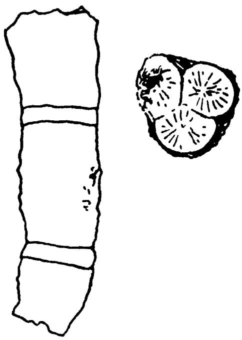
Streptelasma (*Palaeophyllum*) *aggregatum* Nicholson and Etheridge 1880, p. 71, pl. v, figs. 3–3*c*.

Material.—B.M. N.H. R.35125–6.

[1] I have studied the septal structure of the original material of "*Paterophyllum*" *praematurum* Smith, which is of *Streptelasma*-type.

Diagnosis.—Slender fasciculate *Palaeophyllum* with a conspicuous peripheral zone of contiguous septa, axial structure composed of a few isolated septal edges, minor septa long, trabeculae well developed and at a low angle of inclination, tabulae complete and flat.

Description.—This species is represented by numerous cylindrical specimens ranging from 9 to 15 mm. in diameter. The corallites are embedded in a black mudstone matrix and in no case is the epitheca revealed. The calices are deep and filled with black mud. There are 25–26 stout major septa, roughly radial but occasionally flexuous, and nearly reaching the axis. A few stout segments of isolated septal edges form the axial structure. The fibre-fascicles are elaborate and grouped into trabeculae, which project inward from the periphery at a low angle of inclination. Successive expanded portions representing oblique sections of the trabeculae are discernible in the major septa. The minor septa are sometimes discontinuous, or the lowly inclined trabeculae become dissociated from each other. In the longitudinal section the trabeculae are very well revealed, measuring 0·37 mm. in thickness and making an angle of about 70° with the wall. The peripheral zone of contiguous septa is not uniform and has a width about one-sixth that of the radius. Only thirteen flat complete tabulae are present in a vertical distance of 19 mm.



TEXT-FIG. 3.—*Palaeophyllum aggregatum* Nicholson and Etheridge. × 4/5. B.M. R35125.
(*a*) Lateral view of the corallum.
(*b*) Calical view showing central calical budding.

Remarks.—Disregarding the difference in growth form, *Palaeophyllum aggregatum* bears a close resemblance to *Streptelasma craigense* in septal structures especially in the development of the septal trabeculae. Without knowledge of the septal structures of the genotype, *Palaeophyllum rugosum*, it is not possible to speculate on the ancestry of the present species.

Subgenus **Kiaerophyllum** Wedekind 1927

Genotype.—*Kiaerophyllum kiaeri* Wedekind 1927, Upper Ordovician, Norway.

Diagnosis.—Large *Streptelasma* with a prominent anastomosing axial structure formed by the denticulate inner edges of the septa.

Remarks.—*Kiaerophyllum* is very common in, and mostly confined

to, the Upper Ordovician and represents a short-lived specialization of the *Streptelasma* stock. The genotype comes from the Upper Ordovician of Ringerike, Oslo, and Scheffen described several more species from the same region, some of which may well be merged. *Streptelasma robustum* Whiteaves, *Streptelasma arcticum* Wilson, and *Streptelasma foersti* Troedsson are all members of *Kiaerophyllum*.

Kiaerophyllum kiaeri Wedekind

Pl. VII, fig. 2

Kiaerophyllum kiaeri Wedekind 1927, p. 17, pl. i, figs. 7–9.

K. semilunatum Scheffen 1933, p. 21, pl. ii, figs. 4–6.

Material.—B.M. N.H. R.35117.

Diagnosis.—Large trochoid or subcylindrical *Kiaerophyllum* with a prominent peripheral zone of contiguous septa, a conspicuous wide anastomosing axial structure and numerous incomplete arched tabulae.

Description.—This species is represented by several large specimens with marked annulations, averaging 20 mm. in diameter at the distal end. In a lower section measuring 12 mm. there are thirty-nine major septa which reach the axis and are strongly twisted. In the adult stage the septa amount to forty-five in number and the axial zone attains a width one-half that of the diameter. The arrangement and grouping of the fibre-fascicles are as in *Streptelasma craigense*, and a faint development of trabeculae can be observed in the longitudinal section. The peripheral zone is only one-seventh to one-eighth the width of the radius. The inner portions of the major septa are thin and flexuous, and the constituent fibre-fascicles are long and acutely pinnate. The minor septa extend beyond the peripheral zone to one-third the distance to the axis, and are contratingent against the major septa, bending toward the counter and away from the cardinal septum. The tabulae are highly arched in the axial zone and slope down steeply toward the periphery.

Remarks.—Our form agrees very well with the genotype from Norway except in the less numerous tabulae in the peripheral zone.

Kiaerophyllum europaeum (Roemer)

Pl. VII, fig. 1*a*–*b*, Text-fig. 4

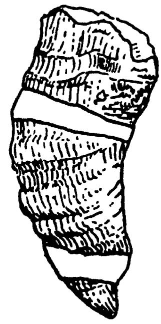
Streptelasma europaeum, Nicholson and Etheridge 1880, p. 76, pl. vi, figs. 1*a*–*b*.

Kiaerophyllum anguineum Scheffen 1933, p. 27, pl. iii, figs. 3–4.

Material.—B.M. N.H. R.35128, 35135–6.

Diagnosis.—Large curved ceratoid *Kiaerophyllum* with strong anastomosing axial structure, a narrow peripheral zone, thin flexuous major septa, and very short minor septa.

Description.—Several curved trochoid coralla over 40 mm. high and 20 mm. in diameter at the distal end represent this species. The proximal sections show dilated septa with twisted axial ends. Virtually there is no marked peripheral zone of contiguous septa. In the adult stage there are forty-three thin and flexuous major septa and a wide axial zone which attains a width one-half that of the diameter and consists of heavy anastomosing tissue overriding the septa. The minor septa are very short and contratingent against the major ones. The longitudinal section shows much resemblance to that of *Kiaerophyllum kiaeri*, but the axial zone of anastomosing tissue is appreciably wider.



TEXT-FIG. 4.—*Kiaerophyllum europaeum* (Roemer). × 1. B.M. R35128.

Genus **Codonophyllum** Wedekind 1927

Genotype.—*Streptelasma milne-edwardsi* Dybowski 1873, Silurian, Gotland.

Diagnosis.—Trochoid or cylindrical, rarely weakly compound corallum, septa thick and entirely contiguous in the peripheral region, major septa long, reaching the axis, minor short, composed of very stout trabeculae with composite sclerodermites, fan-system of trabeculae pronounced, tabulae doomed, close and incomplete, no dissepiments.

Codonophyllum truncatum (Linn.)

Pl. VII, figs. 9*a–c*

Codonophyllum truncatum, Smith and Tremberth 1929, p. 368, pl. viii, figs. 5–7.

Material.—B.M. N.H. R.35133–34.

Diagnosis.—Simple or weakly compound *Codonophyllum* with a wide peripheral zone of contiguous septa in adult stage, major septa reaching the axis and slightly twisted, tabulae highly convex in the axial region and steeply inclined toward the periphery.

Description.—Two well preserved specimens with open funnel-shaped calices were found in the Whitehouse Group. One is 24 mm. in diameter and over 30 mm. high, the other 19 mm. in diameter and 22 mm. high. Septal grooves and faint wrinkles are well marked on the surface. In the distal section there are thirty-three septa reaching the axis and slightly twisted. The minor septa are entirely embedded

in the peripheral zone which has a width one-third that of the diameter. The fibre-fascicles are very elaborate and the trabeculae are excessively stout, arranged in an asymmetrical fan-system truncated by the periphery. Lamellar tissue is present in the peripheral zone and strengthens the fusion of the septa. The longitudinal section displays an axial zone of twisted septal ends simulating that of some *Streptelasma* species. The tabulae are numerous and highly convex.

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EXPLANATION OF PLATE

All figures × 2, figs. 4, 6, 7*b–c* slightly retouched.

FIG. 1.—*Kiaerophyllum europaeum* (Roemer) Barr series, Stinchar Limestone, Craighead, Girvan.
(*a*) Transverse section B.M. R35128*a*.
(*b*) Longitudinal section B.M. R35128*b*.

FIG. 2.—*Kiaerophyllum kiaeri* Wedekind. B.M. R35117*a*. Same horizon and locality.

FIG. 3.—*Streptelasma* cf. *corniculum* Hall. Same horizon and locality.
(*a*) Transverse section, adult stage. B.M. R35129*b*.
(*b*) Transverse section, late ephebic state. B.M. R35129*a*.

FIG. 4.—*Streptelasma rusticum* (Billings). B.M. R35127. Same horizon and locality.

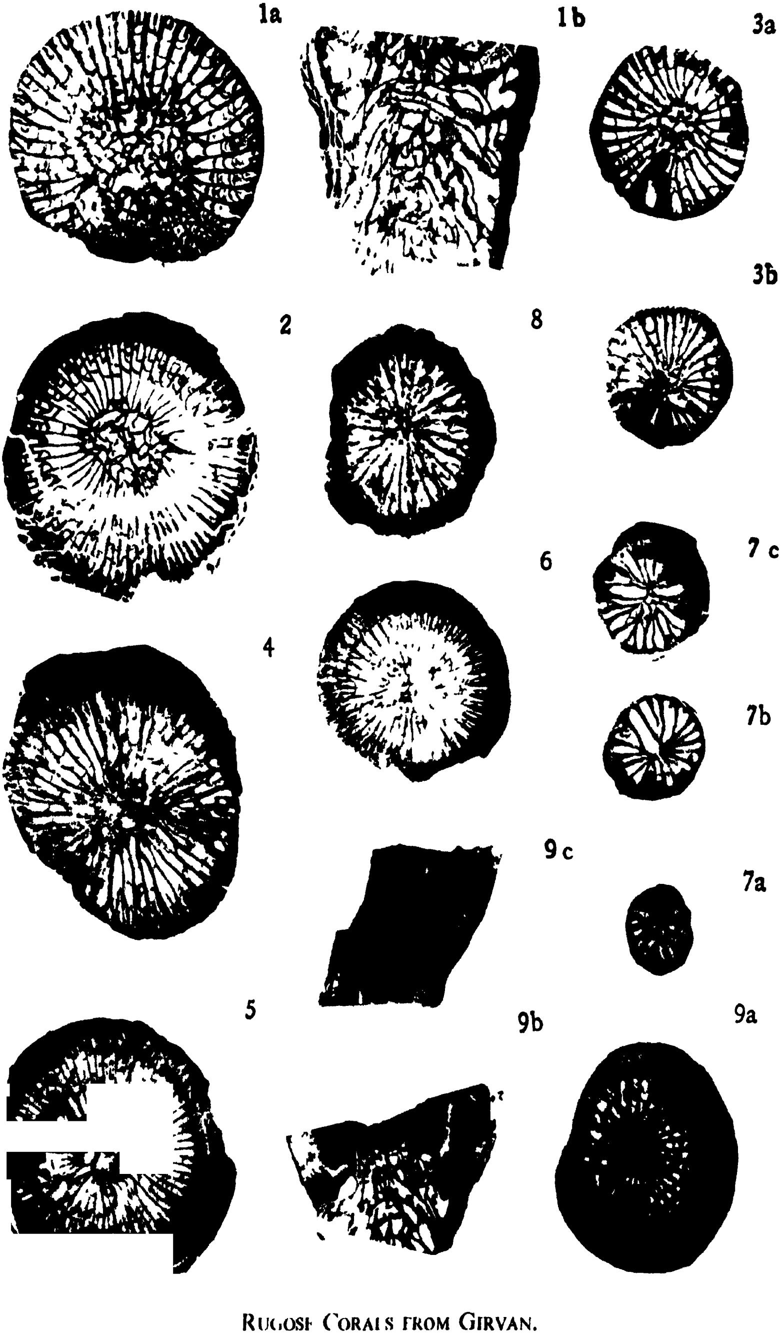
FIG. 5.—*Streptelasma craigense* McCoy. B.M. R35118*b*. Same horizon and locality.

FIG. 6.—The same. B.M. R35113*b*. Same horizon and locality.

FIG. 7.—*Streptelasma fossulatum* sp., nov. Holotype. Balclatchie Group, Lower Ardmillan Series, Balclatchie, Girvan.
(*a*)–(*b*) Transverse sections, ephebic stage. B.M. R35124*a*–*b*.
(*c*) Transverse section, adult stage. B.M. R35124*c*.

FIG. 8.—*Palaeophyllum aggregatum* Nicholson and Etheridge. B.M. R35125*b*. Same horizon and locality.

FIG. 9.—*Codonophyllum truncatum* (Linnaeus). Whitehouse Group, Ardmillan Series, Shalloch Hill, Girvan.
(*a*) Transverse section, adult stage. B.M. R35133*a*.
(*b*) Longitudinal section. B.M. R35133*b*.
(*c*) Tangential section. B.M. R35133*c*.



RUGOSE CORALS FROM GIRVAN.

New Evidence Concerning the Original Order of Deposition of the Longmyndian Rocks

By John Challinor

(PLATE VIII)

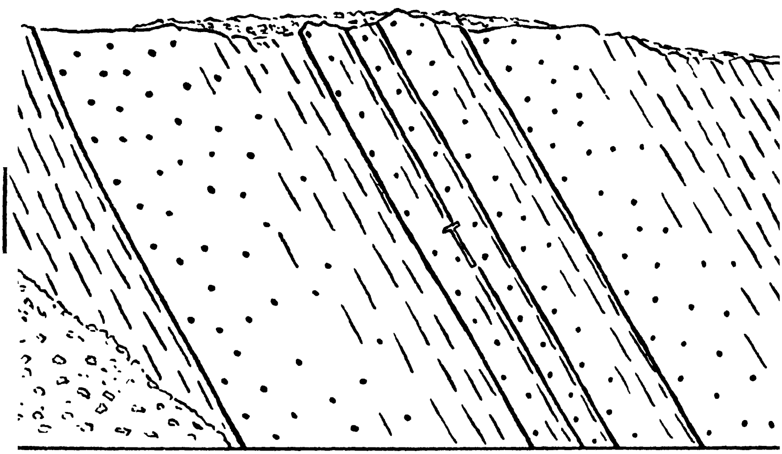
During the war a large new quarry was opened in the Longmyndian rocks of Haughmond Hill, Shropshire. It is near the south-east edge of the hill, to the west of the road running north from Upton Magna and one mile from the village. On the sketch-map in the Shrewsbury Memoir [1] (p. 58) two arrows are shown, at about this locality, recording dips of 50° in a south-easterly direction. I was told that there was a very small quarry here before the large quarry was excavated. The present quarry is even larger than that near Haughmond Abbey (Shrewsbury Memoir, p. 48), on the north-west side of the Pre-Cambrian outcrop, and the two quarries offer extensive and splendidly displayed exposures of Longmyndian rocks, one in the coarse-grained Western Longmyndian and the other in the fine-grained Eastern Longmyndian.

In this new quarry in the Eastern Longmyndian, the rocks are green and purple shales with coarser greenish beds, varying in thickness from a few inches to a few feet, of a fine micaceous sandstone showing folded and crumpled internal bedding. These lithological characters agree with those of the upper part of the " Green Sandstone Group " (Shrewsbury Memoir, p. 43). I have not, however, yet seen any reference to disturbed internal bedding in Longmyndian rocks. The dip is fairly regular, being 60 in a direction E. 40° S., and a true thickness of some 230 feet is exposed.

The chief point of interest about this large new exposure is the evidence it provides as to the original order of deposition of the Longmyndian rocks. The lower surfaces of the coarser beds show, in the dip-section at the north-east end of the quarry, sharp and definite lines ; while upwards these beds grade insensibly into shales (see Text-fig. 1 and Pl. VIII, fig. 1). Now this difference in the degree of definition of the surfaces of a coarser bed is the most conspicuous feature of the well known phenomenon of " graded bedding ", the sharply defined surface being the original lower surface. From familiarity with the Upper Valentian rocks at Aberystwyth, where the feature is everywhere obvious and its significance indubitable, I have no hesitation in saying that in this quarry the rocks can be seen to

[1] R. W. Pocock and others, Shrewsbury District, *Mem. Geol. Survey*, 1938. The other page references, given later in the present article, are also to this work.

be really the " right way up ", though highly tilted (to the south-east). This means that in Haughmond Hill the Eastern Longmyndian both actually and also stratigraphically overlies the Western Longmyndian, with the further implication that in the Longmynd itself, where the



TEXT-FIG. 1.—Diagrammatic sketch, made on the spot, of some of the bedding features present in the rocks shown in the photograph (Pl. VIII, fig. 1). Dots indicate coarser beds, broken lines shaly beds. Contorted bedding not shown.

general dip is steeply north-westward, the succession is an inverted one. This confirms the suggestion of the Geological Survey (pp. 11–13), made on other grounds.

On the side of the small cutting which gives entrance to the quarry from the road, the rocks with their south-easterly dip are bent over rather sharply so as to dip, in the upper part, in the opposite direction (see Pl. VIII, fig. 2). The surface of the ground slopes only very slightly in the direction of overturning and the folding, which is evidently of a superficial and not of a tectonic kind, may have been caused by glacial drag. (The general movement of the ice is known to have been towards the south-east.) Whatever the origin, it is rather curious that this overturning, so conspicuous in one place, is not visible elsewhere. At the back of the quarry, however, the rocks curve upwards slightly, so as to steepen their dip near the surface, and there are some small " thrusts ", with displacement towards the south-east ; but these features may be truly tectonic.

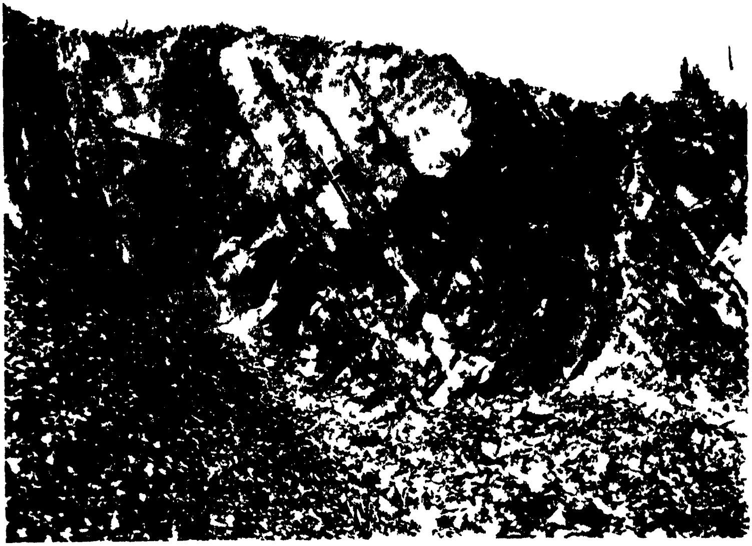


FIG 1

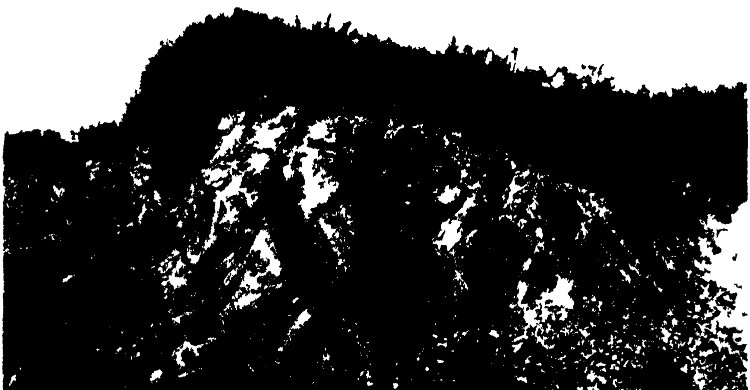


FIG 2

LONGMYNDIAN ROCKS IN THE NEW QUARRY, HAUGHMOND HILL

EXPLANATION OF PLATE

FIG. 1.—Dip-section in Eastern Longmyndian rocks at the north-east end of the new quarry on Haughmond Hill, Shropshire. The sharply defined lines have a coarser bed above (to the right) and a finer bed below (to the left). The finer beds are comparatively thin and they grade downwards insensibly into the coarser beds. The hammer lies along a thin, fine bed which is exceptional in being well-defined, both top and bottom. Compare with Text-fig. 1.

FIG. 2.—Section on the side of the cutting at the entrance to the quarry, showing the superficial bending of the rocks just here. Perspective, and the way the gorse extends rather lower down on the right, cause the photograph to give a somewhat exaggerated impression of the slight slope of the ground to the right. Incidentally, the rocks here, too, show the sharply defined under-surfaces of the coarser beds. The hammer lies along an ill-defined junction between a thick massive coarser bed below and a thin shaly finer bed above.

The Cambrian – Ordovician Junction, Whitesand Bay, Pembrokeshire

By W. David Evans

(PLATE IX)

In 1940 Professor O. T. Jones published in the *Geological Magazine* significant observations on certain of the Lower Palaeozoic contacts in north Pembrokeshire. His detailed inspection of the Solva-Caerfai contact at Caerfai Bay, and the Arenig-Lingula Flag junction at Whitesand Bay, revealed erosional and depositional features which clearly established hitherto debatable lines of unconformity. In addition, his results have aroused much needed assiduity in the interpretation and inspection of formational breaks in the Lower Palaeozoic rocks. Shearing and structural deformities, as well as the emplacement of cleavage, frequently mask such erosional and depositional features but, as Professor Jones has demonstrated, vestiges of them sometimes remain.

During the Geological Society's Instructional Tour for 1947, his Solva-Caerfai contact was inaccessible owing to the tides, but the Arenig-Lingula Flag junction on Trwyn-Hwrddyn, Whitesand Bay, was examined. Here, earlier in the year, I identified channelling in the Lingula Flags (see Pl. IX) at precisely the place where the unconformity with the overlying Tetragraptus Shales has been the cause of considerable controversy in the past. The party of students were taken to this locality on the north side of Whitesand Bay, and during this inspection a " boulder " of Lingula Flags was discovered resting in a highly significant position below the level of the plane of unconformity.

On Trwyn-Hwrddyn the Lingula Flags dip northwards at approximately 80°. The overlying basal sandy facies of the Tetragraptus Shales (similar to the Porth Gain Beds described by Professor A. H. Cox) dip in the same direction, but in a slightly discordant fashion. Complicating the section, as demonstrated by Professor Jones, is a plexus of little strike-faults accompanied by quartz veins. Thus, only for a few yards along the central parts of the westwardly directed promontory of Trwyn-Hwrddyn, is it possible to pin-point the plane of unconformity between the Cambrian and the Ordovician. In fact, as Professor Jones states, it was only after the identity of the striking unconformity between the Lingula Flags and the Tetragraptus Shales had been established on Ramsey Island that similar relationships were observed on Trwyn-Hwrddyn (*Proc. Geol. Assoc.*, xli, 1930, 431).

On the south side of Trwyn-Hwrddyn there is a clear section of a buried channel in the Lingula Flags (Pl. IX). Since the beds dip at

over 80° to the north, a cross section of the channel is revealed in plan in this photograph, which was taken from a slightly elevated crag near by. The walls of the channel are sharply defined and present all the features one would expect from subaqueous channelling into, or coast line erosion of, horizontal beds of laminated sandy mudstones. Near the top of the channel the " solid " Lingula Flags are shattered into thin slabs and rubble—yet another feature of platform erosion of horizontal strata.

Infilling the channel is a confused accumulation of weathered laminated mudstone rubble as well as broken slabs and boulders of pale sandstones. All the material is typically weathered Lingula Flags which has obviously been derived from eroded exposures of this formation. Furthermore, it indicates that the Lingula Flags were in a highly consolidated condition during this period. It is also likely that these more-or-less horizontal deposits were sufficiently consolidated to have developed a joint-system. This would account for the cross-bedding fractures which are associated with the profile of the channel.

The sharp plane of the unconformity identifiable a few yards to the west of the channel becomes ill-defined in the vicinity of the loose rubble of Lingula Flags (see Pl. IX). On the other hand, the darker sediments forming the base of the Tetragraptus Shales can be identified passing over this disintegrated zone of Lingula Flags.

Comparing this section with that described by Professor Jones (*Geol. Mag.*, 1940, lxxvii, 407) there seems little doubt that both these features form part of a single structure. Namely, a channel, or system of channels, infilled with derived Lingula Flag material of Ordovician age. A fault has been responsible for the uplift of the nearby section previously described. In this, it must be noted, the streaky sandy mudstones at the base of the Tetragraptus Shales bank up against the Lingula Flags. On the headland similar deposits form the upper parts of the buried channel. This may be interpreted as indicating that the westerly section is a more deeply incised part of the channel system. Palaeogeographically this means, presumably, that channelling of a planated area of Lingula Flags was being developed in a south-eastwardly direction in pre-Ordovician times in this area. Furthermore, it adds additional weight to the stratigraphical importance of the section evaluated by Professor Jones. Both sections reveal the extent of the pre-Ordovician denudation of what was apparently a block-uplifted area of Cambrian strata of considerable dimensions in Pembrokeshire.

In Professor Jones's section (*Geol. Mag.*, 1940, lxxvii, Text-fig. 1, 407) the lenticular mass of derived Lingula Flag material is similar to the shattered and weathered Lingula Flags forming the upper parts of the channelled rocks. In the same way, the overlying " boulder

conglomerate with coarse sandy matrix", described by Professor Jones, is represented by material infilling the channel. From these and other observations both sections are undoubtedly closely related. Probably the 5 yards of section previously described forms the western wall of the Trwyn-Hwrddyn channel.

Some 10 yards to the west of the Trwyn-Hwrddyn channel is an upstanding " boulder " of Lingula Flags. The bedding in the boulder is inclined at a similar angle to the formation *in situ*. Cementing it to the solid rock is a variable few inches of mudstone rubble with a sandy matrix. This material to some extent wraps around the underside of the " boulder " as well. In all respects the brecciated rubble resembles the material usually infilling open joints in laminated mudstones, and this may be its origin. The joint planes in the " solid " Lingula Flags are developed at right angles to the bedding and roughly parallel to the inner edge of the " boulder ". It has therefore been concluded that this peculiarly orientated " boulder " of Lingula Flags is what remains of this formation originally situated between two steeply inclined open joints. Furthermore, it seems likely that these were formed when the beds were in a more-or-less horizontal position since they are filled by derived Lingula Flag rubble. If this be true, we have here an example of a pre-Ordovician joint system.

The promontory of Trwyn-Hwrddyn is partly concealed by relatively modern raised-beach deposits containing boulders of Lingula Flags and other rock-types. Consequently, the possibilities of this " boulder " originating during this period of platform erosion was not overlooked. In the first place, its uppermost edges lie well below the level of the raised beach. In every way it is apparent that the " boulder " has been revealed by present day coastal erosion. On the other hand, it is most unlikely to have been emplaced in this fashion by the sea. Thus, its position stratigraphically beneath the plane of the unconformity is interpreted as representing yet another feature of the pre-Ordovician erosion and structure of the Upper Cambrian deposits of this area.

I wish to express my gratitude to my colleague, Mr. R. C. K. Blundell, who painstakingly made photographic records of this interesting junction.

EXPLANATION OF PLATE

View of the Buried Channel on Trwyn-Hwrddyn: the stripy beds are Lingula Flags in situ forming the sides of the channel.

Photo by R. C. K. Blundell.

VIEW OF THE BURIED CHANNEL ON TRWYN HWRDDYN.

Peremistocrinus from the Dewey Limestone Formation, Oklahoma

By Harrell L. Strimple

(PLATE X)

THE first systematic study of anal variations found among various Carboniferous crinoids was presented by James Wright (*Geol. Mag.*, lxiii, 1926) and covered *Eupachycrinus calyx* (McCoy) (now *Phanocrinus* Kirk) and *Zeacrinus konincki* Bather. Subsequently (*Geol. Mag.*, lxiv, 1927), the genus *Hydreionocrinus*, and *Ulocrinus globularis* (Geinitz) (now *Ureocrinus* Wright and Strimple, *Geol. Mag.*, lxxxii, 1945) were also considered. A total of 2,014 dorsal cups from the Scottish Lower Carboniferous (Mississippian) were involved in the examinations. These specimens were all from strata considered equivalent to the Chester Series (upper Mississippian) of North America. When presenting the genus *Phanocrinus* Kirk (*Journ. Paleont.*, 11, 1937) recognized the importance of Wright's studies, but noted that examination of an almost equal amount of American material (primarily the Springer collection of the U.S. National Museum) had failed to disclose such great variations. That Kirk was highly impressed by Wright's studies is certain, for in personal conversations, several years ago, he emphasized the potentialities as they might affect my impending studies of Pennsylvanian crinoids. It has, therefore, been with much interest that I have watched similar patterns of development appearing in the large collections being made from both Chester (Upper Mississippian = European upper Lower Carboniferous) and Missouri (Middle Pennsylvanian = European middle Upper Carboniferous) of north-eastern Oklahoma.

Results of a study dealing with *Phanocrinus* from the Fayettville formation (Chester) has previously been given by the author (MS. submitted to *Journ. Paleont.* in 1947). The present paper deals with variations in the posterior interradius of *Peremistocrinus* as found in the Dewey limestone formation, Skiatook Group, Missouri Series, Pennsylvanian. The " crinoid " zone of the Dewey limestone rests near the base of the formation and apparently represents subdivisions C 2 to C 4, of a Missouri Series megacyclothem (see R. C. Moore, Stratigraphic Classification of the Pennsylvanian Rocks of Kansas, *Bull. 22, Univ. Kans.*, p. 34, 1936). This is a blue grey shale, highly bryozoan, and locally has weak impure limestone lenses. Unusual salinity is indicated in that the specimens have a " salty " taste when placed in the mouth or touched to the tongue. There is a rich micro-fauna present, and a " dwarf " fauna including such forms as *Hustedia*

mormoni, *Chonetina flemingi*, *Michelinia* sp., and the unusual crinoid *Allagecrinus strimplei* Kirk—as complete crowns. Larger forms are intermingled, including *Composita subtilita*, *Caninia torquium*, *Lophophyllum* sp., productids and large crinoid column fragments. Large or medium sized crinoid calices are very rare, only 100 partial or complete cups having been found in some twelve years of intensive collecting. Of these, fifty-seven specimens belong to the genus *Peremistocrinus* and exhibit considerable variation in the posterior interradius.

Although the lower portion of the formation is exposed over large acreages by the quarrying operations of the Dewey Portland Cement Company, only rather limited areas present the desired zone. To the south of Bartlesville, Oklahoma, U.S. Highway 75 cuts through the Dewey limestone some 1½ miles from town and an excellent cross-section is formed by the road-cut. The exposure of the basal " crinoid " zone is small but produces occasional crowns of *Allagecrinus strimplei*, and two large dorsal cups have been found. Another local road to the south, known as the " Country Club Road ", cuts through the Dewey limestone and exposes the basal zone quite well. Several crowns of *A. strimplei* have been collected in this outcrop, as well as one or two larger dorsal cups of *Peremistocrinus*. This later outcrop is most interesting in the preservation of large coral colonies, primarily *Caninia torquium*, along with large numbers of brachiopods of the *Composita subtilita* type. The basal " crinoidal shale " is followed by thin layers of limestone for about 10 to 12 inches, then another yellowish shale (clay) zone some 3 feet thick which is rather fossiliferous and becomes saturated with corals as the next limestone band is approached. The underside of the limestone layer is an almost solid mass of corals.

The formation continues to form a low scarp on to the south and is exposed at several places ; however, the only other good outcrop of the basal crinoidal shale, known to the author, is some 2½ miles west of Ramona, Oklahoma, where an east–west county road cuts through the scarp to the base. There are numerous crinoid stem fragments present, and I have observed arm ossicles of *A. strimplei*, but no crinoid calices or crowns have been found. Probably shale washings would yield immature specimens of *A. strimplei*.

For simplicity in comparison the classification adopted by Wright is used here, namely :—

Primitive Type.—All forms in which anal X, at its lower end has more or less wide contact with post. B, and lower end of RA has a similar connection with r. post. B.

Primitive Type A.—As above, but with the lower end of RA detached from r. post. B.

Advanced Type.—Where the RA has a direct connection with l. post. R. and anal X is entirely separated from post. B.

Advanced Type A.—Similar to above, but with lower end of RA detached from r. post. B.

Considerable care has been taken to determine that the critical cup elements have actually lost contact before assigning them to the special " Types ".

SUMMARY OF OBSERVATIONS.

	Primitive Type	*Primitive Type A*	*Advanced Type*	*Advanced Type A*	*Other*	*Abnormal*	*Symmetrical*
AFTER WRIGHT :							
Hydreionocrinus .	125 [1]	3	1	1	0	0	0
Less St. Monans .	65	0	0	0	0	0	0
	—	—	—	—	—	—	—
	60	3	1	1	0	0	0
Zeacrinus konincki	49	5	231	56	0	1	0
Ureocrinus globularia	54	0	480	8	0	0	0
Phanocrinus calyx	771	40	115	67	3	3	1
AFTER STRIMPLE :							
Phanocrinus .	272	1	18	6	0	3	0
Peremistocrinus .	22	18	5	13	0	0	0

Most of the specimens which I have examined may be assigned to *Peremistocrinus impressus* Moore and Plummer (*Univ. Texas Publ.* 3945, 1940) ; however, two specimens are close to *P. obesus* Moore and Plummer, two specimens are decidedly new species, and five other specimens are questionable as to specific determination.

In addition to the developmental trend is the elimination of RX from the post. IR. Out of the fifty-seven specimens studied, the RX has lost contact with RA in seventeen specimens. In most of these instances the RA is obviously tending toward resorption. It is almost certain that the form under consideration did resorb the RA (the tendency is seen in ten specimens examined) and, that normally, when only one large plate remains in the post. IR, it is anal X. This development is best seen in Pl. X, fig. 8, where the RA is almost entirely resorbed and anal X is still a large element retaining contact with post. B., and Pl. X, fig. 9, where the single large anal plate (anal X) is the only anal element left in the dorsal cup. This tendency was recognized in the study of *Phanocrinus* by Strimple (MS. submitted to *Journ. Paleont.*, 1947) and was termed " Developmental Trend A ".

There is another strong tendency involved, as indicated by the specimen illustrated on Pl. X, fig. 13, where we find RA taking on greater

[1] This figure is distorted by the presence of 65 dorsal cups from the " White Limestone " of St. Monans, which appear to be a distinct species, and are remarkably constant in all characteristics according to Wright.

size and moving into dominant posterior position. In the examination of *Phanocrinus* (MS. 1947) this was termed " Developmental Trend C ". An examination of Wright's illustrations indicates this later trend is very strong in *Phanocrinus calyx* and *Ureocrinus globularis*, whereas in *Hydreionocrinus* and *Zeacrinus konincki* the dominant trend is toward resorption of RA.

It should be noted that in the specimens represented on Pl. X, figs. 11 and 12 the post. B takes on an unusual length and anal X is eliminated from the cup while still retaining contact with post. B.

These studies are not conclusive and in many instances specialized arrangements of the plates of the posterior interradius are quite significant. For example, out of the hundreds of specimens of *Apographiocrinus typicalis* Moore and Plummer (1940) examined by the author, in two specimens only does the single anal plate lose contact with the posterior basal. As studies progress and specimens are accumulated, our understanding increases. In the meanwhile we can only observe and interpret the facts as we find them.

EXPLANATION OF PLATE

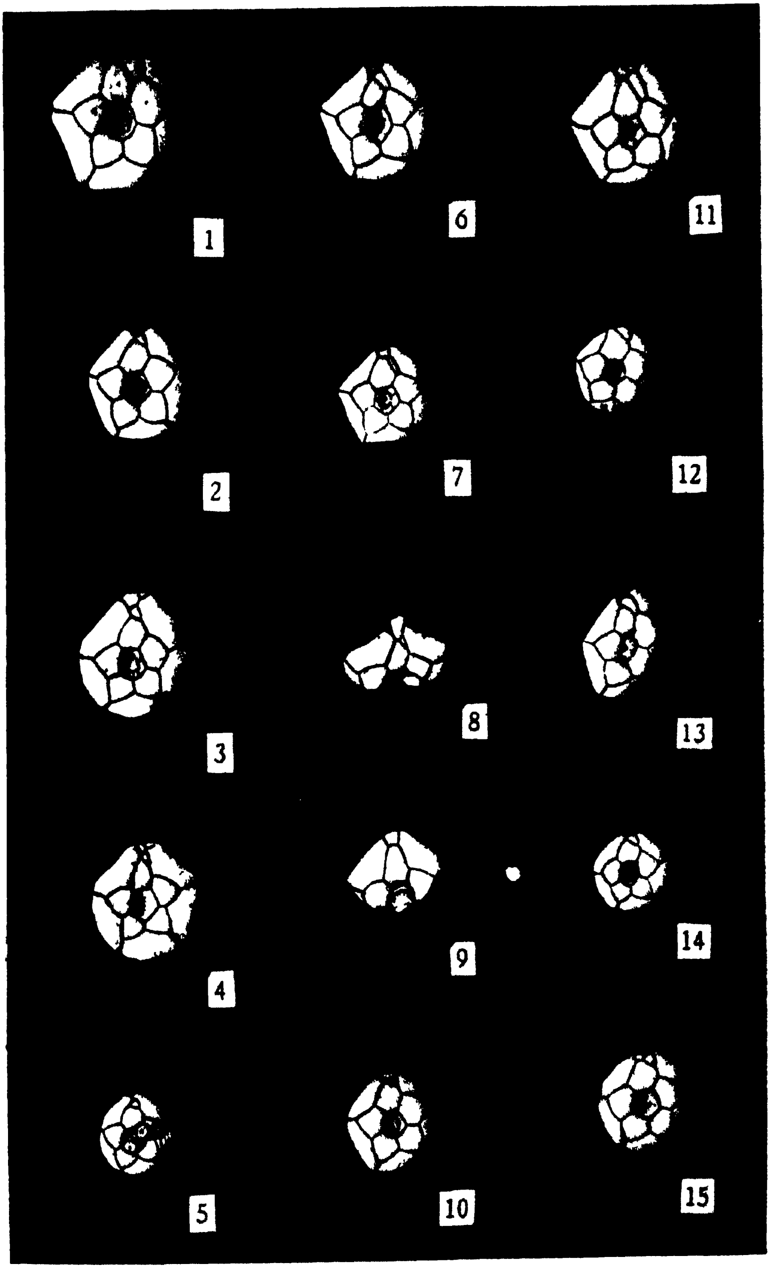
FIGS. 1–15.—*Peremistocrinus*, a typical series of cups from the Dewey Limestone Formation, nat. size. Fig. 1, a typical example of *Peremistocrinus impressus* Moore and Plummer.

ANNOUNCEMENT

X-RAY CRYSTALLOGRAPHY SUMMER SCHOOL

A summer school in X-ray Crystallography will be held in September in the Physics Department of the Manchester College of Technology, under the direction of Dr. H. Lipson. The course is designed to meet the needs of those who wish to make use of X-ray diffraction in both industrial and academic research, but who have not had opportunity to acquire the basic training.

Further details may be obtained from the Director of Extra-Mural Studies, The University, Manchester 13.



H. I. Strimple Photo.

VARIATIONS IN *PEREMISTOCRINUS*.

REVIEWS

ORGANIC EVOLUTION. By R. S. LULL. Revised edition, pp. xx + 744, with 265 text-figures and 31 plates. The Macmillan Company, New York, 1947. Price 40*s*.

The pagination of this new edition seems to correspond exactly with that of 1929 (except for a slight increase in the index) so that presumably the " numerous emendations " noted on the title-page had to be confined to such as would not involve overrunning. One or two new figures have been substituted for old, and the plates are grouped together instead of scattered through the text. Assuming the latter feature was a necessary economy, it is to be regretted that they were placed somewhere near the middle instead of being inserted at the end of the book—surely the natural place to turn and, indeed, the situation noted on p. xix. The price has risen to 40*s*., which is a lot to ask of the student these days, but he gets a lot for it, and it is a pleasure to record that Lull's well-known textbook is once again available. O. M. B. B.

MALAYAN UNION. REPORT OF THE GEOLOGICAL SURVEY DEPARTMENT FOR THF YEAR 1946. By F. T. INGHAM, Director. pp. 58. Kuala Lumpur. Government Press, 1947. Price $1 or 2*s*. 4*d*.

It is pleasing to receive once more the Annual Report of the Geological Survey of Malaya after the disasters of the war period, when all work was naturally at a standstill, all the European members of the staff were engaged on war service, and all but one were either prisoners of war or internees. Moreover, the Japanese looted very thoroughly the head office at Batu Gajah : they removed all the scientific equipment and took away or broke about 5,000 rock slices. Fortunately the rock and mineral collections and the library and records did not suffer quite so badly : eventually they tried to burn down the building, but this was prevented by the Asiatic staff. The district offices also suffered severely. A serious loss was the disappearance of a memoir and map ready for publication, as well as all the relevant notes, so that a good deal of country will have to be re-mapped.

The Report gives details of field work now under way in several areas, but laboratory work was still held up at the end of 1946 owing to want of materials and apparatus. It appears to be still uncertain how many rock-systems there really are in the Peninsula, owing to doubts as to the correlation of two arenaceous formations, one certainly Triassic, the other having so far yielded no fossils. The old familiar name Raub System seems to have been abandoned in favour of Calcareous Formation. It is by no means all limestone.

R. H. R.

GEOLOGY OF THE ANCIENT ROCKS OF CHARNWOOD FOREST. By W. W. WATTS. pp. 160, with plates, maps, and text-figures. Published by the Leicester Literary and Philosophical Society, 1947. To be obtained from G. S. Sweeting, Imperial College of Science and Technology. Price 12*s.* 6*d.* post free.

It is surely exceptional for any man, even a geologist, to work at one subject for over 50 years. That is what Professor Watts did. He went first to Charnwood Forest in 1896, when the area was mapped for the Geological Survey by Charles Fox-Strangways and himself. About the beginning of the century he published two well-known papers on the area and throughout a long and very busy life he retained his interest in it. The result is this attractively written book which, alas, is posthumous, having only reached the stage of proofs when the author died on 30th July, 1947, at the age of 87.

I recollect vividly an excursion from Cambridge to Charnwood with the Sedgwick Club under his leadership about 45 years ago and I went there again about 1914 with Professor Bonney. On these occasions I saw enough to appreciate the complicated nature of the geology. However, with infinite patience Professor Watts has worked it all out, showing that in broad outlines the structure is essentially simple. As he himself writes, not much harm would be done if the whole were regarded as a pitching anticline with a N.W.–S.E. axis. This anticline is faulted in two dominant directions—in plain words, lengthwise and across. Two of the principal longitudinal fractures are overthrusts towards the axis. At the north-west end the structure is obscured by proximity to centres of eruption. Probably most of the rocks are volcanic and one great difficulty in the interpretation of the structure is the correlation of diverse facies of the same age, controlled by varying distance from eruptive centres.

To many people, however, the wonder of Charnwood geology is its buried Triassic landscape, now emerging from its covering of Keuper Marl. Its topography must have been extraordinarily rugged, even where the rocks had been smoothed by wind action as in the Mount Sorrel quarry. All this is illustrated by many beautiful photographs.

There is now no possible doubt that the Charnian rocks are Pre-cambrian, as likewise the structure ; but their exact equivalent is still uncertain. Following upon an opinion expressed by Lapworth, the author would equate them with a division of the Lower (Eastern) Longmyndian. He also refers to the coincidence of strike with the Ingletonians and Lewisians. If the correlation with the Lower Longmyndian is correct, and if, as Lapworth thought, the Upper (Western) Longmyndian is the same as the Torridonian, there can be

no doubt that the Charnians are pre-Torridonian and their folding may belong to the phase that impressed a N.W.–S.E. strike on the Lewisians and Ingletonians. This N.W.–S.E. fold-system, the oldest known in the British Isles, must have been impressed upon the greater part of the country, and indeed traces of its posthumous influence have been detected in many later structures.

Professor Watts also describes the Mount Sorrel granite and its possible satellites, which he accepts as Caledonian. He notes that upstanding parts of this mass are rapidly disappearing, one hill having been entirely quarried away. Owing to the excellent qualities of the Charnian rocks for road metal, doubtfully associated with the abundance of epidote, there is an enormous amount of quarrying; also some of the best exposures have disappeared under reservoirs. Both of these circumstances are much to be regretted, as Charnwood Forest is certainly one of the beauty spots of the country; it is scheduled in the Report of the National Parks Committee as a "conservation area", which means that public authorities have been advised to take measures for its preservation on the lines of a National Park.

I have only one suggestion to make for a second edition, namely, the addition of a topographical map with all the place names mentioned. Even such a well-known locality as Woodhouse Eaves is not marked on any of the maps provided, which makes reading rather difficult for anyone who does not know the geography of Leicestershire.

R. H. R.

GEOLOGY OF HIGHWOOD-ELBOW AREA, ALBERTA. By J. A. ALLAN and J. L. CARR. *Research Council of Alberta Report*. No. 49. pp. 74, with vii plates, 20 figures, and a coloured map. King's Printer, Edmonton, 1947. Price $1.00.

The country described in this report lies in the foothills of the Rocky Mountains, about 45 miles south-west of Calgary. It is almost uninhabited, as it forms part of the Rocky Mountain Forest Reserve. This survey was undertaken on account of the presence of a good deal of coal. On broad lines the geology is very simple, consisting of what is here described as "undifferentiated Palaeozoic" on the west and an almost complete Mesozoic Succession, with glacial deposits, etc. The area has been heavily glaciated and there are indications of river capture and diversions of drainage.

Since the Palaeozoic contains *Spirifer* it is presumably either Devonian or Carboniferous, or both. There is no mention of any Permian. The Jurassic Fernie Formation has yielded a large fauna of Bajocian age, with many ammonites. These are described in an

appendix by Professor P. S. Warren, of the University of Alberta. Coal occurs in the Kootenay Formation, which is here taken as the lowest division of the Cretaceous, though it has been assigned to the Jurassic by other workers. The Mesozoic succession is broken by a number of apparently unimportant local discontinuities or erosion surfaces. Some of the figures show photographs of coal outcrops which seem suitable for open-cast working.

THE BIRTH OF PARÍCUTIN. By J. GONZALEZ and W. F. FOSHAG. *Smithsonian Report for 1946*. pp. 223–234. with 10 plates. Washington, D.C.

On the 20th February, 1943, a volcano started in a field in south-western Mexico while the farmer was at work there with his ox team. By 1946 it had built up a cone 1,500 feet high. The interesting paper quoted above gives a graphic account, largely in the actual words of eye-witnesses, of this very remarkable event. A slight hollow in the field had long been known and near it earth-tremors had been felt and noises heard. A detailed description is given of the course of events which culminated in eruption of ash and bombs and a great lava flow, which together devastated a large area, engulfing two villages at a considerable distance. This remarkable story is clearly genuine as it is vouched for by a well-known American authority and is illustrated by a fine series of dated photographs. It may be added that the locality is not very distant from Jorullo, whose history is known to all volcanologists.

THE MINERAL KEY. By HOWARD B. GRAVES, JR. viii + 178. New York and London: McGraw-Hill Book Company, Inc. 1947. Price 20*s*.

This little book is designed for the amateur mineralogist and has introductory chapters on equipment and chemicals needed and methods of identification. The remainder consists of identification tables in which some eight hundred minerals are arranged, first of all with reference to colour, then with reference to cleavage (in the case of colourless or white minerals) or streak, and the presence or absence of water. Following this the ordinary physical properties, such as hardness, fusibility, and habit, are made use of to identify the mineral, and simple confirmatory tests are given. As the book is intended for amateurs no optical properties are listed. The tables may prove of some value to those mineralogists who have little in the way of laboratory equipment, but the price seems very high for a book of this size, devoid of illustrations.

S. R. N.

GEOLOGICAL MAGAZINE

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The Distribution and Sequence of Carboniferous Coral Faunas

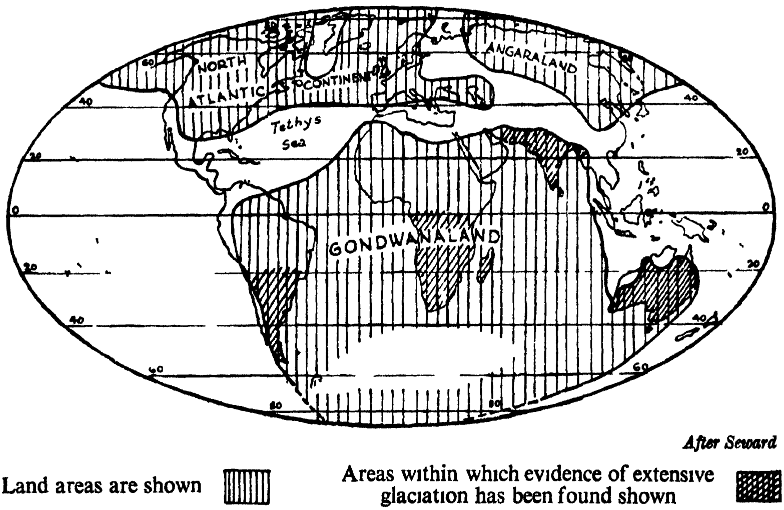
By Dorothy Hill (University of Queensland)

SINCE the beginning of the century Carboniferous corals have been intensively studied throughout the world, and in this paper our resultant knowledge of their distribution and the sequence of faunas is outlined. The lower limit of the Carboniferous is taken to be at the base of the K zone of the Bristol sequence, and the upper limit at the base of the Russian Kungurian stage, in conformity with the principle of priority of nomenclature. The period is thus a long one including the Russian Artinskian, while the Permian is relatively short. Many recent writers, e.g. Dunbar (1940, 1942), adopting criteria other than priority of nomenclature, have extended the Permian downwards to incorporate greater or lesser amounts of the Carboniferous.

Like recent corals, Carboniferous corals associated in faunas with different morphological characters according to the environment (Vaughan, 1909; Hudson, 1924; Hill, 1938–1941; Hudson and Cotton, 1945). Thus the small, solitary non-dissepimented forms of the *Cyathaxonia* fauna seem analogous to the recent fauna of small solitary corals characteristic of cold, deep, or murky seas, while the compound Rugosa and Chaetetida seem to be analogous to the reef corals of to-day, which characterize warm, shallow, pellucid seas. There is, however, a third Carboniferous fauna consisting of large solitary Rugosa with dissepiments (caniniids and clisiophyllids chiefly) which seems to have lived in environments of intermediate beneficence; it is often found with the compound corals, when clisiophyllids usually preponderate, seldom with the *Cyathaxonia* fauna and then caniniids are the more important. Each of these three faunas is characteristic of different sedimentary environments; the first is usually associated with a high percentage of argillaceous or sandy matter in the limestones, and the second with practically pure limestones. Coral reefs of notable thickness seem rare in the Carboniferous, but bryozoan-brachiopod "reef-knolls" are common in Yorkshire and Russia. Compound corals often occur profusely in patches of considerable lateral but little vertical extent.

A. Distribution

Carboniferous coral-bearing strata outcrop chiefly in a remarkable belt in the northern hemisphere between latitudes 20° and 60° N., with a meridional offshoot belt about 60° E. through the Urals and Nova Zembla ; secondary areas are found only in circumpacific lands. The whole coincides with the mobile belts of the period, particularly Tethys and its shelf seas. The distribution is consistent with the theory of the existence of a huge southern continent, Gondwanaland, at the end of the Palaeozoic. With Tethys opening into the Pacific and crossing Eurasia, then (whether or not the equator passed through the same places as to-day) a current of warm water must have flowed



TEXT-FIG. 1 —Map of the world at the end of the Carboniferous Period.

from the Pacific into Tethys, and part of this could have been deflected northwards along the Ural geosyncline. It is thus not surprising that corals, which to-day are chiefly warm water forms, are in the Carboniferous found as far north as Nova Zembla and Spitzbergen.

Zoogeographic provinces are distinguishable in each epoch, with characteristic species and often with a wealth of endemic genera. Provinces were most marked in the Tournaisian and Moscovian. In the Viséan and Artinskian when considerable transgressions of the seas occurred, there were bursts of new species and genera, the coral population was greatly increased, especially the compound Rugosa or " reef " corals, the earlier provinces widened and some merged with their neighbours. The eastern Asiatic part of Tethys (including

South China) was nearly always a distinct province ; likewise the Ural offshoot, although in the Viséan this was extremely closely connected with a West European subprovince. The Mississippi valley fauna was always distinctive. The various sections of the circumpacific belt seem to have been less closely connected than those of Tethys, and Australian, Japanese, and North American Cordilleran corals are generally distinctive, though possessing some elements in common. Then, as now, western Pacific corals seem to have been more prolific than those of the eastern Pacific.

1. Tournaisian

In the Tournaisian the dominant facies-fauna was the *Cyathaxonia* fauna, especially in North America, Europe, and Siberia. The caniniid-clisiophyllid fauna, though sparse, is characteristic ; the preponderance of caniniids over clisiophyllids is notable, but caniniids seem more prone to associate with the *Cyathaxonia* fauna than do clisiophyllids. An interesting feature is the apparent absence everywhere of complex clisiophyllids, *Palaeosmilia* and *Campophyllum* between the Zone d'Etroeungt of Belgium and the upper Tournaisian of Britain. Reef corals are rare in the Tournaisian, but when they do occur they are lithostrotiontids, the earliest occurring with *Endophyllum* in the Zone d'Etroeungt of Nova Zembla. Several of the genera to become important in the Viséan have entered by C_2S_1 times.

Groups of endemic genera are known in North America in the Mississippi valley, in Britain, in Russia, in Siberia, and in China ; and these five regions may be regarded as provinces, of which Britain, Russia, and Siberia had closer relations to one another than to North America and China. In North America the endemic members of the *Cyathaxonia* fauna have discoid, compressed, or calceoloid coralla, in contrast to the normal cornute coralla ; in Britain they have axial structures. Elements of positive value for world-wide correlation are the perforate stratiform Tabulata and *Koninckophyllum* with characteristic straggling axial structure, and their association with ampleximorphs and metriophyllids, *Caninia* with and without dissepiments, and *Cyathaxonia*. That there are these diagnostic forms of wide extent could indicate that rapid migration was possible between North America, Europe, Siberia, and China during the Tournaisian, possibly along the Tethyan shore.

2. Viséan

In the Viséan rich coral faunas are found in Nova Scotia, Australia, and Japan, in addition to those countries where Tournaisian corals have been remarked. There were transgressions of the coral seas and nearly everywhere corals became more numerous and the compound

coral and clisiophyllid-caniniid faunas became dominant. The diagnostic association in all provinces is that of *Lithostrotion* and *Lonsdaleia*, accompanied by a rich clisiophyllid-caniniid fauna which varies with the provinces. In suitable environments such as the Mississippi valley (where it predominates) the *Cyathaxonia* fauna continued to develop, and new species and genera, particularly in the Metriophyllidae and Tachyelasmidae, are numerous.

In Britain, where the biostratigraphy is best known, early members of the fauna entered in C_2 times; more and more new species developed, a maximum of profusion being reached in D_2. There was evidently very free migration between Britain and Russia, for their faunas are remarkably uniform. The association of *Aulophyllum*, *Dibunophyllum*, *Clisiophyllum*, and solitary *Palaeosmilia* is characteristic of this European or *Dibunophyllum* province; the western subprovince has some endemic, short-ranging clisiophyllid genera and clisiophyllids are more numerous than caniniids, whereas in the Russian subprovince caniniids are more important, some being endemic.

In the Chinese or *Kueichouphyllum* province only *Clisiophyllum* occurs of the European clisiophyllids, and the diagnostic forms are instead *Yuanophyllum* and *Kueichouphyllum* with solitary *Palaeosmilia*. Caniniids are few, and European in type. Of the compound corals a number of genera are endemic, while *Lithostrotionella*, common elsewhere only in America, accompanies *Lithostrotion* and *Lonsdaleia*. The Chinese and European provinces overlap in Siberia.

Japan has a small but distinctive fauna. *Lonsdaleia* and *Lithostrotion* occur and the remarkable Heterophylliidae which are known elsewhere only in Europe; there are a few clisiophyllids, one or two endemic genera, the others of Australian or Chinese type. In Australia (the *Amygdalophyllum* province) the clisiophyllids associated with *Lithostrotion* and rare *Lonsdaleia* are endemic except for one of Japanese aspect, caniniids are very rare and no chaetetids are known.

In North America (*Lithostrotionella* province) *Lithostrotion* and *Lonsdaleia* are subordinate to the Chinese *Lithostrotionella*; the few caniniids are of European type, but the *Cyathaxonia* fauna contains some endemic genera. The European *Dibunophyllum* occurs in Nova Scotia and Oregon.

As the Viséan proceeds to its close, smaller numbers of individuals, species, and genera are noted in all parts of the world; no new genera arise between D_3 and Namurian times.

3. Namurian

Namurian coral faunas have been distinguished only in Britain, Siberia, and North America, though their presence seems likely in

other areas (e.g. China) in strata at present referred to the Viséan. They differ from Viséan faunas chiefly by decrease in numbers of genera and species. The only new genera developed are the clisiophyllid *Caninostrotion* in North America (Chester) and Scotland, and a few endemic members of the *Cyathaxonia* fauna in the early Pennsylvanian of North America. In Scotland a number of characteristic new species develops in the *Cyathaxonia* fauna.

4. Moscovian

The Moscovian saw a great reduction in the coral seas. They withdrew from North-West and North Europe and from Eastern North America ; and when they returned there for brief moments only the *Cyathaxonia* fauna existed in them. Elsewhere there was a great decrease in the proportion of compound corals.

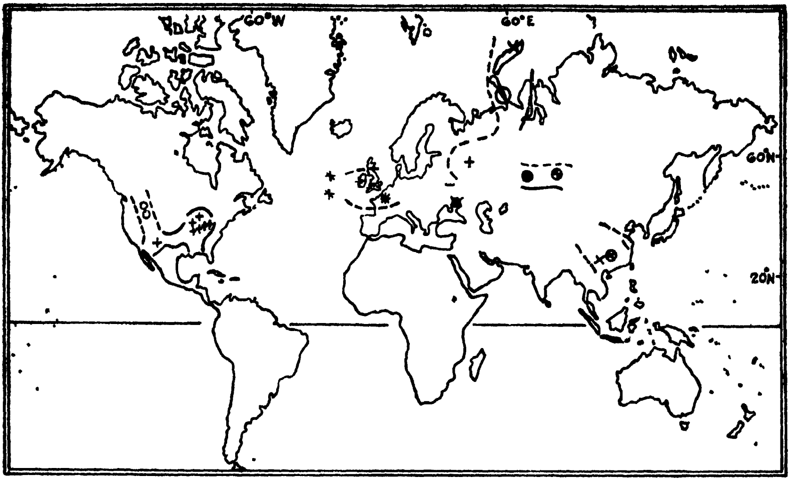
Russia (including Western Siberia) and China both saw developments of the caniniid-clisiophyllid fauna with occasional richness in compound corals, and some *Cyathaxonia* phase, but these two provinces have very little in common. In the western province caniniids are dominant, some continuing from the Viséan, others (e.g. *Timania*) newly appearing. Campophyllids and new clisiophyllids (some like Australian Viséan types) are rare. Compound corals are profuse at only one horizon near the top and are mainly new lonsdaleioids with far less complex axial structures than those of the Viséan, and lithostrotiontids. The *Cyathaxonia* fauna began to be dominated by lophophylloid species. In the Chinese province endemic caniniids are dominant, the few clisiophyllids are amygdalophylloid, while there are survivals of Viséan corals especially lithostrotiontids, lonsdaleioids, and *Corwenia*. The tabulate *Multithecopora* is common.

In small areas lying off these two provinces, in the Carpathians and Japan, small faunas of Viséan aspect are regarded as Moscovian.

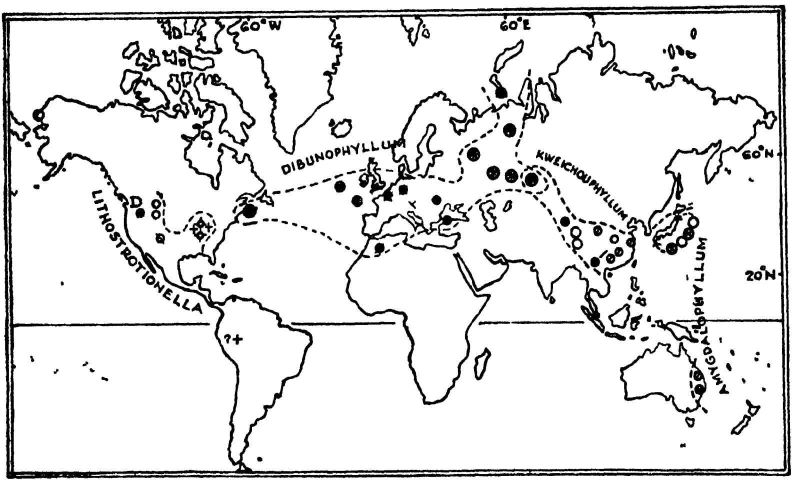
In North America the middle Pennsylvanian is probably Moscovian, with a *Cyathaxonia* fauna mostly lophophylloid. There are occasional caniniids and amygdalophylloids, and *Lithostrotionella* continues in Western States. *Multithecopora* suggests a link with China.

5. Upper Carboniferous *Triticites* Zone (post-Moscovian pre-Sakmarian)

In this zone coral seas are known to have occurred in Russia, Spitzbergen, and the Carnic Alps, and intercalations of *Cyathaxonia* phase in the upper Pennsylvanian of U.S.A. The fauna of each province was distinct, but those of Spitzbergen and Russia were closer to one another than either was to that of the apparently isolated Carnic Alps. In Russia and Spitzbergen phaceloid *Caninia* was the dominant compound coral genus, with subordinate diphymorphic Lonsdaleiidae



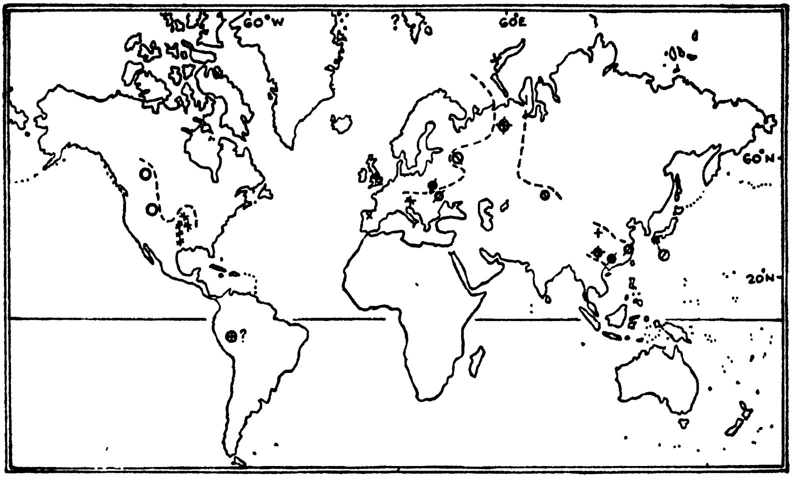
TEXT-FIG. 2.—Tournaisian



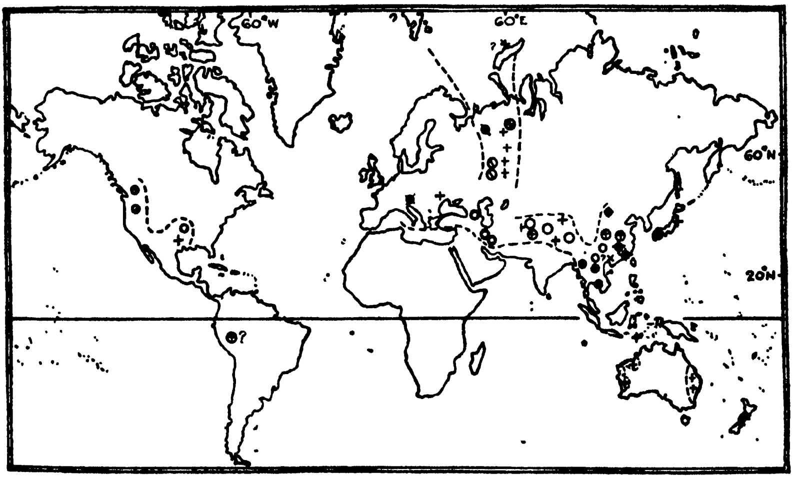
TEXT-FIG. 3.—Viséan.

and Lithostrotiontidae. Caniniids were dominant in the caniniid-clisiophyllid fauna ; in Russia the clisiophyllids were amygdalophylloid, and in Spitzbergen the only one is like the Chinese Viséan *Arachnelasma*. In Spitzbergen *Multithecopora* and *Tetrapora* suggest links with China.

In the Carnic Alps only one compound coral, an endemic genus, is known, and endemic clisiophyllids with amygdalophylloid or symplecto-



TEXT-FIG. 4.—Moscovian.



TEXT-FIG. 5.—Artinskian.

TEXT-FIGS. 2–5. Carboniferous coral localities.

Broken lines represent edges or boundaries of provinces.
Circles = compound Rugosa.
Vertical crosses = *Cyathaxonia* fauna.
Diagonal crosses = Caniniid-clisiophyllid fauna ; N.W.–S.E. line = Caniniids, S.W.–N.E. line = Clisiophyllids.
The symbol of the most important component of any fauna is enlarged.

phylloid axial structures (as in the Australian Viséan) are dominant. Lophophylloids and zaphrentimorphs are typical in the *Cyathaxonia* fauna. The wealth of endemic species and genera suggests isolation.

In North America the *Cyathaxonia* fauna is chiefly lophophylloid and seems to have developed from the earlier Pennsylvanian species.

Elsewhere stratal equivalents of this zone have not been clearly distinguished.

6. Upper Carboniferous Artinskian (including Sakmarian)

In Artinskian times the coral seas once more spread wide and richer faunas developed, particularly compound corals in the schwagerinid limestones of Tethys.

The Russian province is distinctive. In the limestone belts compound corals are dominant, and many new genera enter ; they are cerioid and astraeoid lonsdaleiids with a loose spacious axial structure and often with minor septa imperfectly developed ; although usually referred to the Asiatic genera *Wentzelella* and *Lonsdaleiastraea* they seem distinct from these. In post-Sakmarian times they are joined by numerous diphymorphic lithostrotiontids with imperfectly developed septa. Rare caniniids occur but no clisiophyllids. The sandy facies contains a very rich *Cyathaxonia* fauna of tachyelasmoids, lophophylloids, syringaxonids, metriophyllids, and cravenimorphs (with complex axial structures).

In the Carnic Alps the fauna is still quite distinct from that of Russia. Of the compound corals, one is similar to an American form ; others, lonsdaleoids, are Asiatic rather than Russian in type ; yet others are endemic. Clisiophyllids are characteristic, chiefly with symplectophylloid axial structures, while *Caninia* is rare. The *Cyathaxonia* fauna has tachyelasmoids and lophophylloids.

The narrow Artinskian seas stretching across Asia from Persia to China contained a distinctive fauna. Lonsdaleoids are very numerous, have characteristic neat tightly knit axial structures, and perfect septal development, even tertiary septa occurring ; *Waagenophyllum*, *Wentzelella*, and *Lonsdaleiastraea* with " *Stylidophyllum* " are the chief forms ; Russian-type lonsdaleoids occur with it in Indo-China and China. It is at its richest in the Chihsia limestone of China ; caniniids and clisiophyllids are absent or unimportant, but occasional *Cyathaxonia* phases show tachyelasmoids and lophophylloids. *Tetrapora* appears to have replaced the long-ranging *Syringopora*. The Maping limestone below the Chihsian contains dominant caniniids with some amygdalophylloids and symplectophylloids, and some surviving *Lithostrotion*. This resemblance to the Russian *Triticites* zone rather than to the Artinskian may indicate similar facies rather than similar age. In Japan the fauna is like the Chihsian, but impoverished.

In the Timor province lonsdaleoids (of Asiatic type) are rare, but the *Cyathaxonia* fauna is very rich and mostly like the Russian, though with a rich crop of endemic branching perforate Tabulata. In West Australia the same fauna occurs but somewhat impoverished, and in Eastern Australia and New Zealand only the zaphrentimorph *Euryphyllum* is known with some Tabulata.

In North America the few compound corals are endemic, though one suggests a link with the Carnic Alps ; the *Cyathaxonia* fauna is of typical tachyelasmoid and lophylloid aspect, and rare caniniids occur. Peru may have Artinskian corals.

B. Sequences

Western Europe and North-West Africa

(*a*) *Tournaisian, Viséan, and Namurian.*

In the Lower Carboniferous the coral faunas of Western Europe and North-West Africa belonged to the same province, distinguished throughout by rapid changes in facies in both space and time.

In the British Isles the sequence of faunas has recently been reviewed (Hill, 1938–1941), and additional information has been given by Hudson (1941 to 1945), Hudson and Cotton (1945), Hudson and Fox (1943), Smith (1942), and Smith and Yü (1943). The *Cyathaxonia* fauna was dominant in the Tournaisian until C_2 times. *Allotropiophyllum*, ampleximorphs (probably end points in many Devonian lineages of the trend to radial symmetry and withdrawal of the septa from the axis), caniniids without dissepiments, two genera with axial structures (*Cravenia* and *Rylstonia*), *Cyathaxonia*, various metriophyllids, chiefly with the septa still in contact at the axis, *Menophyllum*, *Cryptophyllum*, *Triplophyllites*, and *Zaphrentites* (Hudson, 1941 ; von Bubnoff, 1926, p. 150), with stratiform perforate Tabulata were all present before C_2. In C_2 all these genera continued except *Menophyllum*, and were joined by the syringaxonid *Permia* and by *Rhopalelasma*, the earliest genus with rhopaloid septa (swollen at their axial ends—a condition which became dominant in the *Cyathaxonia* fauna by the end of the Carboniferous). By S_2D_1 *Cravenia* and the stratiform perforate Tabulata had disappeared, but the other groups continued to develop new species. In D_{2-3} times this development continued, and the Heterophylliidae appeared ; in P_2, E_1 and E_2, the metriophyllids evolved rhopaloid septa withdrawn from the axis, and a lophophylloid columella.

The caniniid-clisiophyllid fauna (Hill, 1938–1941) entered Britain in Z_2, with *Siphonophyllia*, *Caninophyllum*, and *Koninckophyllum*, although it was previously present in Belgium in the Zone d'Etroeungt

in *Campophyllum*, *Caninia*, *Clisiophyllum*, and *Palaeosmilia*. The caniniids particularly *Siphonophyllia* were dominant over the clisiophyllids until the end of the Tournaisian ; one endemic clisiophyllid *Cyathoclisia* had a short range in the Upper Tournaisian, and two others, " *Arachniophyllum* " and *Carruthersella*, occurred only at the boundary between Tournaisian and Viséan. *Carcinophyllum* entered at this boundary, but the clisiophyllids *Dibunophyllum* and *Aulophyllum*, two genera highly characteristic of the European province, entered with *Auloclisia* in the Upper Viséan and quickly developed a host of variations. The caniniid *Bothrophyllum* also entered in the Viséan ; it later became important in Russia in the Moscovian. The only new genus to occur in the British Namurian was the American clisiophyllid *Caninostrotion*, but a number of the old ones, e.g. *Caninophyllum* and solitary *Palaeosmilia* disappeared. *Dibunophyllum*, *Aulophyllum*, and *Koninckophyllum* were still common, but *Carcinophyllum*, *Clisiophyllum*, and caniniids were rare.

No compound Rugosa are known in British K or Z, but in C a few species entered. These were rare *Lonsdaleia*, *Thysanophyllum*, *Lithostrotion*, *Diphyphyllum*, and *Aulina* and in C_2S_1 *Corwenia*. It seems unlikely that they developed from any of the resident *Cyathaxonia* or caniniid-clisiophyllid faunas and although their province of origin cannot be indicated it is suggested that they migrated to Britain as the lower limits of favourable conditions were reached there. The Viséan saw a burst of species of *Lithostrotion*, *Diphyphyllum*, *Nemistium* (an endemic D_2 genus), *Orionastraea*, *Aulina*, *Thysanophyllum*, *Lonsdaleia*, *Corwenia*, and compound *Palaeosmilia*, these genera persisting into P_2 ; usually different species characterize the different horizons. In the Namurian E_2 of Britain, only *Aulina*, *Lithostrotion*, and *Lonsdaleia* are known.

In North-Western and Northern Europe, and on the southern side of the European seas in the Western Sahara the corals are similar to those of the British Isles (Salée, 1913 ; Delépine, 1929, 1930 ; Duterte, 1929 ; Kunth, 1869 ; Paul, 1937, 1938 ; Schindewolf, 1938 ; Weissermel, 1935*a* ; Menchikoff and Hsu, 1935). The Zone d'Etroeungt is of the caniniid-clisiophyllid facies with *Caninia*, *Clisiophyllum*, and solitary *Palaeosmilia* and *Syringopora* (Paul, 1937*b*). Later Tournaisian corals are chiefly of the *Cyathaxonia* fauna, while the fauna of the Viséan is mostly caniniid-clisiophyllid with compound corals. The fauna is not so rich as in Britain, but the genera and many of the species are the same. Only two non-British genera occur—the lower Viséan (S) phaceloid lithostrotiontid *Dorlodotia* (with lonsdaleioid dissepiments), and the solitary Viséan *Humboldtia*, with the corallum elongated in the counter-cardinal plane as in Russia (Paul, 1937–8 ; Delépine, 1929).

(*b*) *Moscovian.*

Two short coral-bearing marine intercalations occur in Britain in the Moscovian (Westphalian) zones of *Gastrioceras cancellatum* and *Anthracoceras aegerinum*, each with a *Cyathaxonia* fauna not greatly changed from earlier British faunas (Smith, 1931). In Spain the clisiophyllid *Amygdalophyllum* appears (Weissermel, 1935*b*); this genus was characteristic of the Australian province in the Upper Viséan, but was not then known in Europe.

Russia in Europe

(*a*) *Tournaisian, Viséan, and Namurian.*

Here Tournaisian corals are few; in the Upa limestone of Central Russia (= Etroeungt of Western Europe), *Z. konincki* occurs with *Aulopora*, *Syringopora*, and *Michelinia*, while in the upper Tournaisian C_1^1b of the Donetz Basin a cerioïd *Lithostrotion* is recorded with *Caninia* and *Syringopora* (Bubnoff, 1926). In Nova Zembla in beds regarded by Gorsky (1935) as of the Zone d'Etroeungt columellate compound corals, possible ancestors for Lithostrotiontidae or Lonsdaleiidae, occur with the Devonian *Endophyllum.*

The Viséan is widely developed, is rich in corals, and as in Britain the caniniid-clisiophyllid and compound coral faunas are dominant (Stuckenberg, 1895, 1904; Perna, 1923; Sokolov, 1939*b*). The *Cyathaxonia* fauna includes *Cyathaxonia*, *Permia*, *Lophophyllum*, *Triplophyllites* (as *Menophyllum* sp.), *Sychnoelasma*, metriophyllids (*Z. helmersoni*), *Cyathaxonella* (perhaps of the *Rylstonia* group), *Cladochonus*, and *Heterophyllia*. The caniniid-clisiophyllid fauna is rich in the characteristic European genera *Aulophyllum*, *Dibunophyllum*, and *Clisiophyllum* with *Koninckophyllum* (as *Lophophylloides*) and *Carcinophyllum*, while *Palaeosmilia* and *Campophyllum* are also common. In the Urals caniniids are commoner than clisiophyllids, many species of *Caninia* resembling *juddi* and *benburbensis* especially having been described with *Pseudozaphrentoides* (= *Caninia*). Three endemic caniniids are *Keyserlingophyllum*, *Uralinia*, and *Humboldtia*. Of the compound corals, *Lithostrotion* and *Lonsdaleia* are both very common, but *Diphyphyllum* seems rarer than in North-West Europe. *Orionastraea* appeared earlier than in North-West Europe in D_1 (Sokolov, 1939*b*). *Thysanophyllum* occurs, and *Corwenia* (as *Chonaxis* or "*Fischerina*"), with compound *Campophyllum* and *Palaeosmilia*. Several genera or subgenera of Chaetetids are recorded (Sokolov, 1939*a*); *Syringopora* is very common, while *Michelinia* is infrequent.

(*b*) *Moscovian.*

The Russian marine Moscovian is quite rich. In the Moscow Basin corals occur chiefly in the upper horizons (Stuckenberg, 1888;

Dobrolyubova, 1935, 1937 ; Kabakovich, 1937), but in the lowest, Vereya horizon (C_2^1), the caniniids characteristic of the middle and upper Carboniferous of Russia, *Bothrophyllum* (known earlier in the British Viséan) and *Timania*, are already present but rare. In the Kashira horizon (C_2^2), *Bothrophyllum* becomes very common, and *Timania* continues ; no clisiophyllids are known and the *Cyathaxonia* fauna is sparse. In the Podolsk horizon (C_2^3), *Timania* has not been recognized, but *Bothrophyllum* (very common) and *Campophyllum* occur, while clisiophyllids are represented by *Koninckocarinia* and a species referred to *Cyathoclisia*. The only compound Rugosa is the aphroid lonsdaleiid *Ivanovia podolskiensis*, with primitive axial structure and concave tabular floors ; chaetetids and *Syringopora* return.

In the Myachkovo horizon (C_2^4) there is a very rich fauna of columellate massive species, referred to the lonsdaleiids *Lithostrotionella*, *Cystiphora*, and *Lonsdaleia*, and the lithostrotiontid *Cystiphorastraea* (Dobrolyubova, 1935), that, from the extension of its major septa to the columella and its small tabellae arranged in tent-like floors, could well be a Moscovian *Orionastraea*. These lonsdaleiids are distinguished from Viséan types by their far less complex axial structures (an elongated counter columella, with rare lateral septal lamellae and sparse tabellae instead of the earlier elaborate spider web) and by their tendency to lose the walls between corallites. Chaetetids and *Syringopora* occur with them. *Bothrophyllum* (here very common) and *Caninophyllum* are accompanied by the clisiophyllids *Amandophyllum* (Heritsch, 1941), *Amygdalophyllum* and *Axophyllum* and other rarer forms. The *Cyathaxonia* fauna is again sparse. In the Donetz basin the Moscovian fauna is similar (Fomitchev, 1938).

From the Northern Urals Dubrolyubova (1936*b*) has described a *Cyathaxonia* fauna of *Lophophyllum* spp. (with a counter columella), *Amplexus*, a metriophyllid like the subgenus *Rotiphyllum*, and *Verbeekiella*—the earliest record for this genus. Phaceloid *Campophyllum uralicum* (of the *C. juddi* group), and " *Fischerina* " are figured also ; the latter may be related to the upper Carboniferous *Tschussovskenia* which indeed occurs with *C. uralicum* on the Stshuger River.

(*c*) *Upper Carboniferous* (*above Moscovian and below Sakmarian*).

In the Moscow Basin, above the Moscovian, after a break in the sequence (possibly represented by the *Wedekindella* zone of the Samara bend bores), there is a thin development of Upper Carboniferous. No compound corals occur, but the solitary corals are distinctive. In the basal *Teguliferina* horizon (C_3^0) Dobrolyubova (1940) figures *Bothrophyllum* (very common) and rare *Timania*,

Campophyllum, and *Amygdalophyllum*. In the C_3^1 Gshelian the Caniniid *Gshelia* is characteristic—a large form with a bar-like columella in young stages which fails in the adult—and members of the *Cyathaxonia* fauna (*Pseudobradyphyllum* spp.) are common, with rare *Cyathaxonia*. This sequence represents the lower part of the *Triticites* zone of the Southern Urals (Dunbar, 1940).

In the Samara Bend of the River Volga, the coral fauna from the *Triticites* zone has not been revised recently, but from Stuckenberg's figures (1905) it evidently consists at the Czar's Barrow (Tzarew Kurgan) largely of the caniniids *Bothrophyllum*, *Caninia nikitini*, and *C. lonsdalei*, the clisiophyllid *Axophyllum*, a few members of a *Cyathaxonia* phase including *Cladochonus*, and reef corals including the phaceloid *Caninia volgense* and *Campophyllum volgense* with the Tabulates *Syringopora* and *Michelinia*, and *Chaetetes*.

A reef coral fauna which is believed to be above the Moscovian but below the "*Schwagerina*" zone (Sakmarian) has been described from the Verdkne-Tschussovskaya-Gorodki Borehole No. 2, from below 910 to 1,250 metres (Dobrolyubova, 1936*a*; Soshkina, Dobrolyubova, and Porfiriev, 1941). It is distinguished from the Moscovian fauna by the tendency to lose the columella. Of the lonsdaleiids, *Lithostrotionella* and *Thysanophyllum* continue from the Moscovian. Of the Lithostrotiontidae, *Orionastraea* is common, and species placed in *Cystiphora* in which the columella is still present suggest by their arched tabular floors that they are of this family. The only phaceloid form is *Tschussovskenia*, with a *Nemistium*-like axial structure and a narrow, irregularly developed dissepimentarium (not lonsdaleoid).

(*d*) *Upper Carboniferous* (*Artinskian*).

The "*Schwagerina*" zone (often renamed the *Pseudoschwagerina* zone) or Sakmarian, the lower part of the Artinskian (Dunbar, 1942), is rich in corals (Dobrolyubova, 1936*a*, *b*; Soshkina, Dobrolyubova, and Porfiriev, 1941). Its commonest forms in the Shikkans of the Sterlitamak are cerioid Lonsdaleiids which have been assigned to *Wentzelella* but should perhaps be regarded as a separate genus. Their major septa are usually slightly thickened in the tabularium, their minor septa are often imperfectly developed, and there is a loose axial structure consisting of a median plate and a few irregular side plates, reinforced by small highly inclined axial tabellae; these characters are in contrast to those of typical *Wentzelella* from the Salt Range, where the septa are thickened in a peripheral stereozone, tertiary septa may appear, and the axial structure is a neat web of tightly packed tabellae and lamellae. Astraeoid developments of these Russian *Wentzelella* have been referred to *Lonsdaleiastraea*, but differ

from typical Timor *Lonsdaleiastraea* in the same ways. Several of the species met in the *Triticites* zone at Verdkne Tschussovskya Gorodki still exist in the Shikkans, such as *Tschussovskenia captiosa*, and a cerioid *Thysanophyllum*. *Caninophyllum* occurs, and *Amplexicarinia*, a member of the *Cyathaxonia* fauna.

In succeeding Artinskian horizons in the Sterlitamak Hills this fauna is joined by a variety of massive species, all without columella and with major septa withdrawn from the axis, while may also lose their minor septa. The cerioid forms have been referred to *Diphystrotion* and *Thysanophyllum*, the astraeoid forms to *Cystiphora* and *Orionastraea*. From the arched or tented or flat tabulae, it seems that the species placed in *Diphystrotion*, *Cystiphora*, and *Orionastraea* are degenerate Lithostrotiontidae. These diphymorphic forms are highly characteristic of the Russian upper Artinskian.

Karpinsky's type section for the Artinskian was in the Orenburg region (Dunbar, 1942), and Soshkina, Dobrolyubova, and Porfiriev (1941) have figured corals therefrom. Those from the basal calcareous beds (Sakmarian) are close to species from the "*Schwagerina*" zone of the Sterlitamak while species occurring in sandstone on the Kargala River referred to the Artinskian, are similar to those of the post-"*Schwagerina*" beds of the Sterlitamak. In the upper stages of the Artinsk series of Aktiubinsk, and *Paralleynia* occur. At Krasnoufimsk the Tabulate genera *Monotubella* and *Pseudofavosites* are found (Yakovlev, 1939).

From beds of non-calcareous facies outside the type area regarded as Artinskian by Russian authors, we have a number of small solitary types, all members of the *Cyathaxonia* fauna (Soshkina, Dobrolyubova, and Porfiriev, 1941). Their chief feature is the rhopaloid septum seen in *Tachyelasma* (including "*Hexelasma*"), *Plerophyllum* (including *Sochkineophyllum* and "*Pentaphyllum*"), and Gerthia (including *Phryganophyllum* and "*Polycoelia*"). Syringaxonids, showing an aulos, are *Lytvelasma*, *Amplexicarinia*, and *Paralleynia*; while a group of lophophyllidioids includes *Sinophyllum*, *Timorphyllum*, and *Lophophyllidium*. A cravenimorph with an axial structure of complex type is *Verbeekiella*. The Metriophyllidae are represented by *Lophelasma*, and also recorded is the zaphrentimorph *Meniscophyllum*.

In the Northern Urals, large caniniids of the type common in the Gshelian (e.g. *Timania*, *Caninophyllum*) and phaceloid *Campophyllum* occur in limestones interbedded with shales carrying this *Cyathaxonia* fauna. The facies is overlain by clear limestones containing the reef corals and forams of the *Parafusulina lutugini* zone of the Sterlitamak (Soshkina, Dobrolyubova, and Porfiriev, 1941). Some suggest that the *P. lutugini* zone may represent the basal Kungurian (Maximova, 1945).

The *Cyathaxonia* fauna is represented in the dolomites with "*Schwagerina*" of the Donetz Basin by *Lophophyllidium.*

Spitzbergen

Upper Carboniferous.

Heritsch (1939) considers that the Myachkovo stage (Upper Moscovian) is represented here together with Pennsylvanian and "*Schwagerina*" zone equivalents. Characteristic is the large number of phaceloid caniniids and the fact that all the massive Rugosa are cerioid, the epitheca between individuals being well developed. Lithostrotiontids are present in *Siphonodendron*, and "*Orionastraea*" (cerioid and diphymorphic). Lonsdaleiidae are represented by "*Petalaxis*" (= *Cystiphora* of Dobrolyubova in part) and *Lithostrotionella*, which occurs in King's Bay, and indicates to Heritsch the presence of Moscovian. The only clisiophyllid is the Chinese *Arachnelasma*, but the Caniniidae are present in great force; in addition to seven phaceloid species Heritsch describes *Timania* and large solitary species of *Caninia*, including *C. nikitini* and *C. calophylloides*, which recalls the Chinese Namurian *Kueichouphyllum*. Members of the *Cyathaxonia* fauna are *Gerthia*, the metriophyllid *Bradyphyllum*, *Tachyelasma*, *Hapsiphyllum*, *Zaphrentoides* (= *Caninia*), and *Amplexicarinia*. The Tabulata are *Chaetetes*, *Syringopora*, *Multithecopora*, and "*Tetrapora*" (known in China in "*Schwagerina*" zone equivalents), *Cladochonus* and the micheliniid *Roemeripora*. To me this fauna seems characteristic of the beds above the Moscovian and below the "*Schwagerina*" zone of the Russian sequence. The cerioid and solitary forms typical of the "*Schwagerina*" zone in Russia or Asia are absent.

Carnic Alps

Middle and Upper Carboniferous.

Heritsch (1936*a*) shows that the Carnic Alps is distinguished as a province by clisiophyllids with symplectophylloid or amygdalophylloid axial structures. The lowest Avernig beds he correlates with the Myachkovo horizon of the Moscovian; they contain *Amplexicarinia* and *Caninia*.

In the higher Avernig beds he distinguishes two successive upper Carboniferous pre-"*Schwagerina*" zone faunas. In the first the *Cyathaxonia* fauna is represented by the metriophyllids *Lophelasma* and *Lophocarinophyllum* with *Sinophyllum* and *Amplexicarinia*. There is one caniniid, *C. nikitini* and a large number of endemic clisiophyllids with axial structures like those of the Australian Viséan *Symplecto-*

phyllum or *Amygdalophyllum*, such as *Zelaeophyllum*, *Carinthiaphyllum*, *Carniaphyllum*, and " *Carruthersella* ". These are associated with dissepimented and atypical " *Lophophyllidium* " and " *Lophophylloides* ", with *Amandophyllum* having repeated axial plates (known also from the Moscovian of Russia), and an atypical " *Dibunophyllum* ". One compound coral occurs, the phaceloid " *Palaeosmilia* " *demaneti*, whose septal structure reminds one of *Aulina*. In the uppermost Avernig beds, this fauna is joined by the zaphrentimorphs *Bradyphyllum*, *Hapsiphyllum*, and *Allotropiophyllum*. *C. nikitini* is replaced by *C. stuckenbergi*, and " *Carruthersella* " by the amygdalophylloid *Geyerophyllum*, while " *Palaeosmilia* " disappears and *Syringopora* enters.

The Rattendorf beds are correlated by Heritsch with the " *Schwagerina* " beds of Russia. The lower strata contain *Lophocarinophyllum*, *Amplexicarinia*, and *Allotropiophyllum*, dissepimented " *Lophophyllidium* ", and the symplectophylloids *Carinthiaphyllum*, *Clisiophyllum zeliae*, and *Zelaeophyllum*. *Caninia sophiae* is the characteristic caniniid. Compound corals are two cerioid lonsdaleiids of Asiatic type, with endemic *Lonsdaleoides* (like a phaceloid *Symplectophyllum*), " *Palaeosmilia* " *ampfereri* (which is compared by Heritsch, 1936*d*, with an American species from the Saddle Creek limestone of Texas and considered to be derived from caniniid stock) and " *Corwenia* ". A slightly higher Rattendorf fauna contains dissepimented, columellate species placed in *Rossophyllum* and *Lophophyllidium*. From the red Trogkofel Limestone above the Rattendorf beds, Heritsch (1934) lists *Tachyelasma*, *Amplexicarinia*, and *Sinophyllum*. He correlates it with the Artinskian of Russia, the Chihsian of China, and the Word Formation of U.S.A.

Styria and the Carpathians

Heritsch (1933) has described British types of *Carcinophyllum*, *Caninophyllum*, and *Palaeosmilia* from an Upper D zone in Styria. A small fauna of Clisiophyllids (*Koninckophyllum*, *Dibunophyllum*) and phaceloid *Lithostrotion* from the Carpathians is regarded as Moscovian (stage of Myachkovo) and compared with species from the Weiningian of China (Heritsch, 1935).

Asia Minor

Charles (1933) has described a fauna from Anatolia whose species are very similar to the common forms of the Viséan of North-West Europe.

Western Siberia

(*a*) *Lower Carboniferous.*

Corals from the Kousnetzk coal basin and the neighbouring Kirghiz Steppe are regarded as Tournaisian in greater part ; but some are correlated with the *Seminula* stage of the Lower Viséan, and a very few with the Upper Viséan near the D_1–D_2 boundary (Gabounia, 1919 ; Tolmatchoff, 1924, 1931 ; Fomitchev, 1931 ; Gorsky, 1932 ; and Ilyina, 1939). The *Cyathaxonia* fauna resembles that of the British Isles, as does the bulk of the caniniid-clisiophyllid fauna. In this caniniids are dominant, but there are some clisiophyllids of Chinese type, chiefly *Clisiophyllum* and *Koninckophyllum*, while " *Rhodophyllum dubium* " may be the Chinese *Kueinchouphyllum.* An endemic caniniid is *Aenigmatophyllum.* Of the compound corals, cerioid lithostrotiontids with and without columella and with lonsdaleoid dissepimental borders occur. Those without columella are called *Stelechophyllum.* Normal cerioid and phaceloid *Lithostrotion* occur and *Diphyphyllum.* According to Ilyina, phaceloid *Lithostrotion* enters here in the Tournaisian earlier than elsewhere. The figures suggest an aulos in some corallites and a columella in others. Chaetetida are absent from the Kousnetzk basin (Sokolov, 1939*a*), but *Syringopora* and *Michelinia* occur with the cleistoporid *Yavorskia.* Krestovnikov (1940) records *Lithostrotion* and a species like *Palaeosimilia regia* from the Namurian of Kazakhstan.

(*b*) *Moscovian.*

Moscovian caniniids and lonsdaleiids occur near Lake Balkhash (Vakhrameev and Rausser-Chernoussova, 1938).

Persia and the Karakorum

? *Upper Carboniferous* (*Artinskian*).

Douglas (1936) has described some interesting Persian corals with neat, spider-webbed and columellate axial structures. Solitary and phaceloid forms are *Iranophyllum, Waagenophyllum,* and *Yatsengia* and massive forms are *Stylidophyllum, Wentzelella,* and *Polythecalis.* The latter he considers represent the Chihsia limestone fauna of China, and the former the fauna of the " *Schwagerina* " beds of Russia. The Persian corals are all Asiatic in character and this mode is also found in the Eastern Karakorums where typical *Waagenophyllum, Wentzelella,* and *Lonsdaleiastraea* occur with " *Stylidophyllum* ", chiefly in a red *Lyttonia* limestone (Gerth, 1938). Gerth correlates the beds with the Crinoidal *Lyttonia* limestone of the Middle *Productus* Limestone (Virgal group) of the Salt Range.

Afghanistan, India, and Tibet

? *Upper Carboniferous (Artinskian).*

In the Salt Range *Wentzelella* and *Waagenophyllum* have their type development, accompanied by *Michelinia*, in the Middle *Productus* Limestone, but *Waagenophyllum*, accompanied by *Michelinia*, continues into the Upper *Productus* Limestone, where large numbers of *Thamnopora* occur (Waagen and Wentzel, 1886 ; Sen, 1931, 1932 ; Smith, 1935 ; Heritsch, 1937). The stratigraphical equivalents in Russia of these *Productus* limestones are not certain ; but possibly the Middle *Productus* Limestone at least is Artinskian. Both *Waagenophyllum* and *Wentzelella* occur in the Chitral (Reed, 1925 ; Smith, 1935). In the Southern Shan States, *Waagenophyllum* and *Wentzelella*, with *Iranophyllum* (as *Chonaxis*), *Campophyllum*, and *Syringopora* occur with "*Schwagerina*" in Tibet (Reed, 1930), while *Tachelasma* and *Syringopora* occur with *Neoschwagerina* and rare "*Schwagerina*" in Afghanistan (Reed, 1931).

Indochina

Upper Carboniferous (Artinskian).

In Cambodge, Indochina, the *Wentzelella* species are of Russian rather than Salt Range type (Mansuy, 1913) and *Lonsdaleia s.l.* is very abundant (Gubler, 1935). A cerioid species from Luang Prabang has been referred to the Timor species *W. timorica* by Gerth (1921).

China (including Chinese Turkestan and Mongolia)

(*a*) *Lower Carboniferous (Fengninnian).*

The earliest Rugosa recognized in China are of the caniniid phase, the endemic *Cystiphrentis* stated to have septa inserted in the counter sectors as well as in the usual four positions, occurring with *Syringopora* in the Kolaoho Limestone. Another Tournaisian caniniid phase follows with the endemic *Pseudouralinia*, a second genus with the counter sectors larger than the cardinals, but with the septa withdrawn from both periphery and axis ; the clisiophyllids are represented by *Koninckophyllum* of British late Tournaisian type and *Syringopora* and *Michelinia* are both common (Yü, 1933, 1937 ; Chi, 1933).

In Viséan and Namurian limestones, the *Cyathaxonia* fauna seems poorly represented (Grabau, 1928). The caniniid-clisiophyllid fauna is very rich, with the clisiophyllids greatly preponderating and the genera are different from those of the European province ; thus typical *Dibunophyllum* does not occur, but is represented by two endemic Chinese genera *Arachnelasma* and *Yuanophyllum* ; *Aulophyllum* is absent and *Clisiophyllum* has developed several Chinese characteristics.

There is an endemic fauna of *Kueichoùphyllum*, *Yabeella* (both with long minor septa) and *Heterocaninia* without minor septa, which are possibly clisiophyllids. Solitary *Palaeosmilia* is present and the few caniniids are like British types.

Of the reef corals, *Aulina*, described by Smith and Yü (1943), perhaps indicates the presence of Namurian ; *Lithostrotion* with *Diphyphyllum* predominate over *Lonsdaleia* and their species are European in character. Cerioid *Lithostrotionella*, the type species very like that of *Thysanophyllum*) occurs with phaceloid *Thysanophyllum* to which an endemic phaceloid genus *Kwangsiphyllum* without dissepiments minor septa or columella may be related. Typical *Corwenia* is present. The phaceloid aulate *Diphyphyllum* ? *vesicotabulatum* and the cerioid aulate *Crepidophyllum yohi* are noteworthy, with ? *Prismatophyllum* ; the two latter suggest derivation from Devonian species.

(*b*) *Middle Carboniferous* (*Weiningian*).

Chinese geologists regard the Huanglung, Moukou, Laokanchai limestones, and others as Moscovian. Their fauna is rich, with little in common with the Russian Moscovian faunas (Grabau, 1928 ; Lee, Chen, and Chu, 1930 ; Chi, 1931, 1935*a* ; Yü, 1934). The *Cyathaxonia* fauna is of *Bradyphyllum*, *Hapsophyllum*, *Gerthia*, *Sochkineophyllum* (elsewhere regarded as Artinskian), *Lophoprentis*, and *Meniscophyllum*. Caniniids seem to dominate over the amygdalophylloid clisiophyllids *Cionophyllum* and *Axophyllum*. *Bothrophyllum*, dominant in Russia, appears rare in China, as does *Gshelia*. A solitary *Palaeosmilia* and some dibunophyllids survive from the local Lower Carboniferous fauna. *Orionastraea*, phaceloid *Lithostrotion*, and *Stylostrotion* occur, and *Corwenia* survives with cerioid *Lithostrotionella* and *Lonsdaleia*. An aphroid form with a laterally ridged columella has been placed in *Cystiphora*. *Syringopora*, *Multithecopora*, and *Chaetetes* are all common.

(*c*) *Upper Carboniferous*.

In the Maping Limestone which has been correlated with the Russian "*Schwagerina*" beds caniniids are again dominant ; but *Amygdalophyllum* and the symplectophylloid *Sinophyllum* ? *nantanese* Yü occur, while some "*Carcinophyllum*" suggest *Iranophyllum* of Persia. The *Cyathaxonia* fauna is sparse, *Duplophyllum* and *Bradyphyllum* being recorded (Chi, 1938). The phaceloid *Lithostrotion perpetuum* seems the last of this genus in China. In the equivalent Chuanshan Limestone *Cystiphora* is recorded (Yü, 1934), and the cerioid, endemic, *Cyathophyllum cystitabulatum* (Huang, 1932*b*).

In the Chihsia Limestone and its widespread equivalents, all younger than the Maping, there is a very rich fauna (Yoh and Huang, 1932 ;

Huang, 1932*a* ; Chi, 1937, 1938). The *Cyathaxonia* phase is well represented by *Tachyelasma, Paracaninia, Caninia* without dissepiments, *Sinophyllum, Timorphyllum, Allotropiophyllum,* and *Cladochonus.* The clisiophyllid-caniniid fauna is almost completely absent, but there is a great wealth of the compound corals, *Michelinia* and *Tetrapora* (which appears to have replaced *Syringopora*). Phaceloid forms with axial structures are very common ; some are *Waagenophyllum* of Salt Range type ; others (*Corwenia*) of American (*Heritschia*) type ; while the slender *Yatsengia* has its typical development. Of the cerioid forms at least three morphologies are distinguishable, Asiatic *Wentzelella,* Russian *Wentzelella,* and *Stylidophyllum volzi* auctt. The aphroid *Polythecalis,* which seems to have developed from Asiatic cerioid types is extremely common.

In Mongolia the Jisu Honguer Limestone which Grabau (1931) equates with the Middle *Productus* Limestone of the Salt Range and the " *Schwagerina* " beds of Russia, contains " *Polycoelia* ", *Amplexus,* and *Waagenophyllum.* In Chinese Turkestan a fauna with *Sinophyllum* and *Tachyelasma* described by Chi (1935*b*) may be equivalent to this.

Japan

(a) Viséan.

A phaceloid *Lithostrotion-Diphyphyllum* fauna, probably Viséan, is present in Kyusyu and again in the Onimaru Series in the Kitakami mountains, where it is accompanied by cerioid *Lonsdaleia,* by sparse clisiophyllids including possibly the Chinese *Kueichouphyllum,* by *Syringopora* and *Chaetetes,* and the interesting *Hexaphyllia* and *Heterophyllia* known elsewhere only from Russia, Europe, and Britain (Yabe, 1939 ; Yabe and Sugiyama, 1939*a*, *b*, 1940).

The Omimura limestone of Echigo contains at its lowest horizon columellate clisiophyllids like the Australian *Amygdalophyllum* and *Axophyllum gracile,* with cerioid *Lonsdaleia* and *Lithostrotion,* and the phaceloid *Waagenaphyllum omiense* (= *Corwenia* ?). An Upper Viséan age has been suggested (Hayasaka, 1924). *Orionastraea* is recorded from Central Japan (Hayasaka, 1932).

Low in the Akiyosi limestone of Nagato are *Nagatophyllum* (a clisiophyllid affected by the *Naos* septal trend), a phaceloid symplectophyllid (*Lonsdaleia enormis*) and " *Polycoelia* " species ; at a slightly higher horizon this symplectophyllid is associated with cerioid *Lonsdaleia* (Ozawa, 1925).

(b) Moscovian.

A little higher in the Akiyosi limestone *Nagatophyllum* is associated with Fusulines considered Moscovian (Yabe, 1939) ; higher still a cerioid *Lonsdaleia* occurs with *Dibunophyllum.*

(*c*) *Upper Carboniferous.*

In the zone of *Pseudoschwagerina princeps* the phaceloid *Lonsdaleia katoi* and the cerioid *L.* (*Wentzelella*) *yokoyami* occur and in the zone of *Schwagerina lutugini*, which Yabe (1939) regards as basal Permian, *Waagenophyllum akaskense.*

Malaya and Timor

(*a*) *Viséan.*

Viséan corals are recorded from Bukil Charas, Kuantan in Malaya (Smith in Scrivenor, 1931); *Cyathaxonia*, *Caninia*, a clisiophyllid and a diphyphyllid occur.

(*b*) *Upper Carboniferous* (*Artinskian*).

In Timor there is a remarkably rich *Cyathaxonia* fauna, probably the richest known anywhere (Gerth, 1921; Koker, 1924). Specialized endemic Tabulata which appear to have been derived from *Thamnopora*, *Striatopora*, and *Cladochonus* are common. Different stratigraphic horizons cannot yet be distinguished on corals alone; but the fauna from Basleo and neighbourhood is the richest, and is usually regarded as Artinskian. Of the solitary Rugosa, many genera have been recognized elsewhere, such as *Timorphyllum*, *Plerophyllum*, "*Polycoelia*," *Gerthia*, *Verbeekiella*, and some specialized forms with large columellate axial structures, but others have not. Such are *Timorosmilia*, two genera with a few dissepiments (one, *Prosmilia*, possibly derived from *Plerophyllum*, the other *Endoamplexus*), and a species placed by Koker (? erroneously) in the Hexacoral genus *Pinacophyllum*. These four Koker places in the Hexacoral family Amphiastraeidae Ogilvie because of the details of septal structure. Another species from Timor she places in the Hexacoral genus *Omphalophyllia*. These interesting suggestions of Hexacoral affinity have not been confirmed. Gerth (1926) describes the *Cyathaxonia* fauna as a warm water coral sward fauna; he regards the general skeletal thickening which they show as typical of the reef zone, and considers equatorial conditions obtained.

The caniniid-clisiophyllid fauna is absent from Timor except possibly for *Endoamplexus*, but compound Rugosa occur in localities different from the *Cyathaxonia* fauna; they are Asiatic in type—*Wentzelella* and *Lonsdaleiastraea.*

Australia and New Zealand

(*a*) *Viséan.*

Corals occur in profusion on one horizon in Eastern Australia equivalent to D_2 of the Upper Viséan or possibly younger (Hill, 1934, 1943). It is largely a lithostrotiontid fauna, the species of *Lithostrotion*

s.s. being comparable with those of Germany. *Aphrophyllum* is endemic, *Lonsdaleia* is very rare, and the clisiophyllids are represented not by the characteristic European *Clisiophyllum*, *Aulophyllum*, and *Dibunophyllum* at all, but by the columellate *Amygdalophyllum* and by the endemic *Symplectophyllum* with a complex thickened axial structure. The tabulates *Michelinia*, *Syringopora*, and *Palaeacis* are important in some limestones ; *Cyathaxonia* is rare. Caninimorphs are rare, but occur in New South Wales, incorrectly ascribed by Etheridge (1891) to *Aulophyllum*, *Campophyllum*, and *Zaphrentis*.

(*b*) *Upper Carboniferous* (*Artinskian*).

In the Permo-Carboniferous the *Cyathaxonia* fauna is present, but no compound Rugosa or members of the Clisiophyllid-Caniniid fauna are known. In Eastern Australia and New Zealand *Euryphyllum* is usually the only solitary Rugose genus present, with *Thamnopora* and *Cladochonus*, but *Plerophyllum* has recently been found in Queensland (Gigoomgan). In West Australia the fauna is richer, and includes *Euryphyllum*, *Plerophyllum*, *Tachyelasma*, *Gerthia*, and *Verbeekiella*, while the tabulates *Thamnopora* and *Cladochonus* are important (Hill, 1937, 1938, 1942).

North America

(*a*) *Mississippian* (= Dinantian and Early Namurian).

Here corals are usually of the *Cyathaxonia* fauna, but from a few localities the caniniid-clisiophyllid fauna is known ; compound Rugose corals occur, though not profusely.

The Kinderhook and Osage groups of the Mississippian of the Mississippi Valley are correlated with the Tournaisian, and the Chouteau limestone (which contains most of the corals) with the Z zone (Grove, 1935 ; Bassler, 1937 ; Easton, 1944*b*). Here discoid *Microcyclus*, a topshaped *Hadrophyllum* and *Metriophyllum* continue from the Devonian. Endemic genera are the button-shaped *Baryphyllum* and *Dipterophyllum*, the calceoloid *Homalophyllites*, the degenerate looking *Pseudocryptophyllum*, *Meniscophyllum* (though this may be represented in Ireland by *Heptaphyllum* Clark) the compressed *Clinophyllum* and *Neozaphrentis*. *Cyathaxonia*, *Triplophyllites*, and the metriophyllid *Rotiphyllum* make their first appearance here. Amplexmorphs are present, and the syringaxonid *Crassiphyllum* (= *Permia*) (Hudson 1945*b*). The Tabulata are perforate stratiform cleistoporids with *Cladochonus*, *Pleurodictyum* (= *Michelinia*), *Palaeacis*, and *Microcyathus*. The last *Favosites* occur here. Of the caniniid-clisiophyllid fauna only *Caninia* *Vesiculophyllum* and *Koninckophyllum* are known with *Syringopora*. The only compound Rugosa is early *Lithostrotion*.

In the Rocky Mountain region of Idaho and Montana, Hayasaka (1936) lists the Chinese *Lithostrotionella*, including an aulate species from the Madison Limestone which is equivalent to Kinderhook and Osage (Williams and Yolton, 1945). This seems the earliest occurrence of this genus and indicates an approach to reef facies there. In New Mexico *Caninia* cf. *cornucopia* and *Triplophyllites* occur in Kinderhook equivalents (Jeffords, 1943 ; Grove, 1935).

The coral fauna of the Meremac group of the Mississippi Valley seems from Greene's (1898–1906), Miller's (1892), and Beede's (1905–6) descriptions and figures to be of *Cyathaxonia* phase ; it is rich in *Hapsiphyllum* (Simpson, 1900 ; Grove, 1935), and contains *Enallophyllum* (with an aulos), *Bordenia* and *Cystelasma*, all of which require elucidation, together with the Tabulata *Cladochonus*, *Michelinia*, *Palaeacis*, *Ceratopora*, *Protopora*, and *Syringopora*. In the St. Louis limestone cerioid *Lithostrotionella* is common and characteristic (Hayasaka, 1936) with phaceloid diphymorphic *Lithostrotion*.

In the Rocky Mountain States of U.S.A. the thick Brazer limestone contains three coralliferous horizons correlated with the Warsaw, the Meremac (probably St. Louis limestone), and the Chester ; *Lithostrotion* and *Lithostrotionella* occur in a probable St. Louis equivalent associated with goniatites which suggest an upper Viséan or early Namurian age (Kelly, 1942 ; Easton, 1945*b* ; Williams and Yolton, 1945). In Oregon there is a *Dibunophyllum-Lithostrotion* fauna of European Upper Viséan type in the Coffee Creek Formation (Merriam, 1942) ; in Montana in the Yakinikak limestone *Caninia* and *Triplophyllites* with *Lithostrotion* cf. *irregulare* suggest the Viséan (Sloss, 1945).

In Nova Scotia an Upper Viséan (D zone) fauna of impoverished European type occurs with *Dibunophyllum*, *Caninia*, *Triplophyllites*, *Bothrophyllum*, *Koninckophyllum*, and phaceloid *Lonsdaleia* (Lewis, 1935). Sloss (1945) considers this Chester.

In the Chester Series of the Mississippi Valley ampleximorphs are characteristic of the lower members with *Caninia* and *Palaeosmilia* cf. *regia* (Easton, 1943*a*, 1945*c*). At the top, in the Kinkaid Limestone, Easton (1945*a*) has described the metriophyllid *Kinkaidia*, *Triplophyllites*, and *Caninostrotion*. This limestone he correlates with the Pitkin of Arkansas, which has a similar fauna with in addition *Lonsdaleia*, *Koninckophyllum*, and *Pleurodictyum* (Easton, 1943*a*). This appears to me to be equal to coral zone 3 of Scotland at the oldest, and is possibly Namurian. In Montana Sloss (1945) described *Caninia* from the Amsden Formation, and Easton (1945*b*) *Caninia* and *Triplophyllites* from the Otter. From a Mississippian portion of the Rundle Limestone of Alberta, Canada, Kelly (1942) described *Lithostrotion* and *Lithostrotionella*.

(*b*) *Pennsylvanian* (Upper Namurian to base of Sakmarian).

Lower Pennsylvanian corals from the southern mid-continent regions of the U.S.A. are entirely of the *Cyathaxonia* phase, and are largely endemic, e.g. *Stereocorypha*, *Barytichisma*, *Empodesma*, and the discoid *Cumminsia*, though *Lophophyllidium*, *Hapsiphyllum*, *Amplexi-carinia*, and *Paracaninia* occur in Eurasia ; the curious clisiophylloid caniniids called *Pseudozaphrentoides*, *Neokoninckophyllum*, and *Rhodophyllum* recall the European Tournaisian Clisiophyllids found with the *Cyathaxonia* fauna. *Cladochonus*, *Multithecopora*, *Palaeacis*, *Michelinia*, *Striatopora*, and *Thamnopora* (as *Acaciapora*), with *Chaetetes* show that the Tabulata development proceeded as in Eurasia. This fauna extends from the Upper Namurian into the Moscovian according to American correlations (Jeffords, 1942 ; Moore and Jeffords, 1945).

In the Middle and Upper Pennsylvanian this *Cyathaxonia* fauna continued in the Mid-Continent region, but the corals described are chiefly *Lophophyllidium* with *Stereostylus* and *Lophamplexus* (Jeffords, 1942, 1947), though the discoid *Gymnophyllum* is recorded from the Mid Pennsylvanian of Oklahoma (Howell, 1945). Caniniids occur in Iowa and Missouri (Easton, 1944*a*), and in Kansas where they are associated with amygdalophylloids (Keyes, 1894).

Pennsylvanian compound corals (*Lithostrotionella*) have been described from the Rundle Limestone of Alberta, Canada (Kelly, 1942), and the Weber quartzite of Wyoming (Hayasaka, 1936).

(*c*) *Upper Carboniferous* (Wolfcamp and Leonard Formation).

In beds with *Parafusulina* and *Schwagerina* in Central Oregon there is a reef coral facies with the phaceloid *Heritschia*, cerioid forms placed in *Lithostrotionella*, and a *Caninostrotion* ? (Merriam, 1942). Possibly a similar horizon is represented in British Columbia, where *Heritschia* occurs with *Caninia* (Smith, 1935). In Alaska *Lithostrotionella* occurs in the Carboniferous (Hayasaka, 1936). In Kansas *Heritschia* occurs in the Wolfcamp Series (Moore and Jeffords, 1941). The *Cyathaxonia* fauna of the Wolfcamp Series is found in Texas where *Malonophyllum*, *Lophophyllidium*, *Lophamplexus*, and *Sochkineophyllum* occur, with, at a different locality, the caniniid " *Palaeosmilia* " *schucherti* (Moore and Jeffords, 1941). In the Leonard Series in Texas the *Cyathaxonia* fauna continues, with *Malonophyllum*, *Leonardophyllum*, *Timorphyllum*, and *Duplophyllum* (Moore and Jeffords, 1941 ; Okulitch and Albritton, 1937).

South America

A small *Cyathaxonia* fauna from Viscachani, Peru, consists entirely of lophophyllidioid types and has been regarded as topmost Viséan,

but may well be later (Douglas, 1920, 1936). From Bolivia (Tarma), Meyer (1914) records *Stylastraea conferta*, a phaceloid *Lonsdaleia* (cf. *Heritschia*) with small solitary corals and *Chaetetes*. Dunbar and Newell (1946) state that part of the Tarma sequence is Moscovian (= Des Moines). In Brazil, at Tapajos, *Lophophyllum proliferm*, and a phaceloid *Lonsdaleia* (s.l.) occur in rocks regarded as upper Carboniferous (Katzer, 1935).

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Late Sillimanite in the Migmatites of Kildonan, Sutherland

By Janet Watson

Introduction

A LARGE part of Central Sutherland is occupied by an injection complex in which rocks of the Moine Series are associated with much granitic and pegmatitic material. These migmatitic Moinian rocks have reached a higher grade of metamorphism than those which occur outside the injection complex. One feature characteristic of the high-grade migmatites is the presence of sillimanite in many of the pelitic and semi-pelitic rocks. Near the village of Kildonan, ten miles north-west of Helmsdale, sillimanite is not only abundant in the country rock, but occurs also in many pegmatitic and aplitic veins. The field and microscopic evidence shows that this mineral was formed as a result of metasomatic activity at a late stage in the history of the injection complex, when the general metamorphism was already on the wane. The sillimanite seems to have no direct connection with the conditions of regional metamorphism. It was formed under the influence of pegmatitic solutions. In view of the common use of this mineral as an index of the grade of regional metamorphism, it is of interest to describe the evidence on which the above conclusions are based.

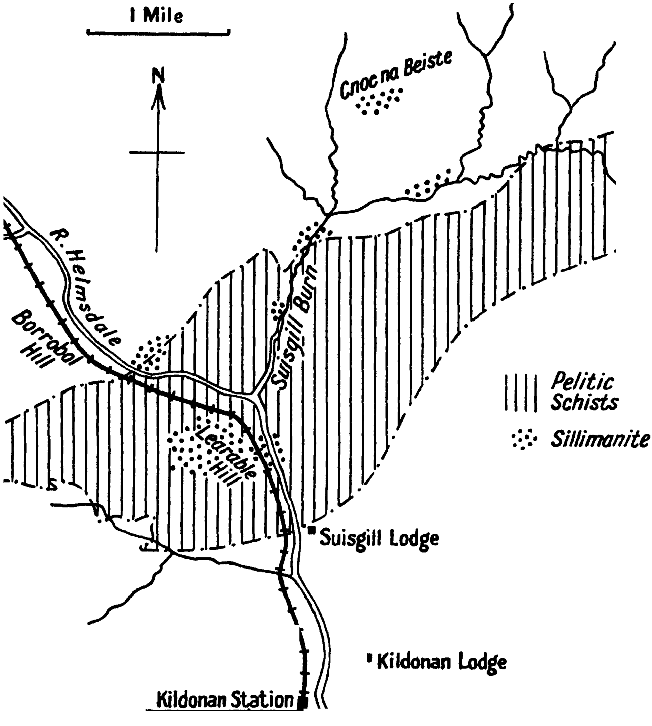
General Geology of the Kildonan Area

The first thorough account of the East and Central Sutherland rocks was given by Horne and Greenly (1896). These authors described the crystalline rocks of the Kildonan district and showed that, from south to north, the following changes could be traced :—

Increase in the quantity of granite.
Intimacy of relation between the granite and its host.
Increase in the coarseness of the schists.
Appearance and perfection of crystallization of sillimanite.

Read (1931) separated the Central Sutherland migmatites into two areas. The eastern part, which he named the Strath Halladale Injection Complex, extends from within a few miles of the north coast of Scotland, southward to the Strath of Kildonan. Part of the complex consists of coarse foliated granite, and the remainder of injected Moinian rocks, traversed by thick sheets of foliated granite. Near Kildonan, which lies at the southern edge of the complex, the degree of injection-metamorphism decreases rapidly from north to south ; two miles north of the village the rocks are thoroughly veined and permeated

and contain abundant fibrolite ; at Kildonan itself granite veins are few, and the country rock is composed of schists and granulites comparable with many Moine rocks outside the injection areas ; fibrolite is not present.



TEXT-FIG. 1.—Sketch Map of the Kildonan Region.

All the sillimanite of the Kildonan district is present as the variety fibrolite.

DISTRIBUTION AND STRUCTURE OF THE COUNTRY-ROCKS

The host rocks of the injection complex include derivatives of the following types :—

1. Pelitic schists.
2. Semipelitic granulites.
3. Quartzites and quartz-felspar granulites.
4. Garnetiferous hornblende-schists.

The hornblende-schists, which probably represent premetamorphic intrusions, are of little importance.

The sedimentary rocks (Text-fig. 1) occur in three main belts, trending north-east or east, and dipping steeply to the south-east or south. The most southerly belt (left blank on the map) crosses the River Helmsdale at Kildonan, and consists of massive pink granulites with almost no biotite. A narrow band of flaggy biotitic granulites provides a transition to the central pelitic belt which stretches from Learable Hill to the lower reaches of Suisgill Burn. On Cnoc na Beiste, to the north-east, these rocks are replaced by semi-pelitic granulites containing abundant knots of *quartz sillimanitisé* or *faser-kiesel.* North of Suisgill Burn the pelitic rocks pass through flaggy granulites into coarse siliceous granulites (left blank on the map) which outcrop in the River Helmsdale and on Borrobol Hill. Except for the stream beds and a few glaciated hilltops the ground is covered with drift, and the exposures are therefore rather disconnected.

The rocks show strong minor folding on axes pitching south or east. Folding probably took place early in the history of the rocks, but some movement was still going on during the late stages of metamorphism. The gneisses are sometimes sheared, and felspars in the migmatites may be bent or broken.

Superimposed on the original sedimentary differences of composition are the variations caused by the addition of material and changes in the conditions of metamorphism. The migmatite front seems to have moved southward. The Kildonan granulites and the southern part of the Suisgill pelitic belt are little affected by injection-metamorphism ; the pelitic rocks are in the garnet grade. As the Suisgill belt is followed northward over Learable Hill the rocks become gneissose and develop conspicuous tufts of fibrolite. The Borrobol granulites, similar in composition to those at Kildonan, are coarse-grained rocks, striped with innumerable thin bands of red granite. The first of the large sheets of Strath Halladale granite occurs at the mouth of Suisgill Burn. Further to the north the granite sheets thicken and unite, engulfing their sedimentary host.

Effect of Migmatization on the Host Rocks of the Complex

A. *Pelitic Rocks*

All stages in the transformation of mica-schist to granite-gneiss can be seen in the Suisgill pelitic belt. Even the least-altered types—the garnet-muscovite-biotite-schists near Suisgill Lodge—contain a good deal of felspar. On Learable Hill the abundant flakes and augen of felspathic material give the rock a gneissose texture. Many weathered surfaces are roughened by projecting masses of fibrolite needles. Thin veins of fibrolite, sometimes mixed with quartz, traverse the country-rock, and knots and veinlets of the mineral are present in

some of the aplites and pegmatites. Around the mouth of Suisgill Burn the gneisses are still more felspathic and pass imperceptibly into the sheets of foliated granite. Fibrolite is rather scarce.

B. *Semipelitic Rocks*

The granulitic semipelitic rocks are speckled with parallel flakes of black biotite. Large flakes of black and white mica coat the flaggy parting planes. The granulites are not very susceptible to injection-metamorphism. The most conspicuous change that they undergo is the development of white knots of quartz and fibrolite, known as faserkiesel. The best exposures of these rocks are found on Cnoc na Beiste. The grey granulite is closely set with flattened or spherical bodies, each about half an inch across ; the rock is figured by Read (1931, p. 160). Faserkiesel does not occur on the east side of Cnoc na Beiste, where the country-rock contains no biotite. Elsewhere the knots are arranged in strings or bands following the foliation and are flattened parallel with the foliation. Micaceous films in the granulite do not bend round the knots, but end abruptly against them. Sometimes a string of knots is replaced along the strike by a small pegmatite or by a fibrolite-bearing vein. Fibrolitic veins occasionally cross the foliation. Similar knots and veins occur in some pegmatites.

Several bands of pelitic gneiss are interbedded with the Cnoc na Beiste granulites. The fibrolite in them is not mixed with quartz, but forms pearly mats like those in the Suisgill rocks. The pelitic rocks pass gradually into the semipelitic ones. As the amount of biotite decreases and the schistosity grows less well-marked the fibrolite mats become mixed with quartz and swell up until they attain the dimensions of faserkiesel knots. The habit of the mineral is apparently controlled by the texture of the host rock.

Faserkiesel is found at several other localities where semipelitic granulites occur within the injection complex. It is usually associated with fibrolite-bearing veins that penetrate the sedimentary and granitic parts of the complex.

Veins of the Complex

Sheets of granite, ranging in thickness from a few inches to several yards, are common, especially in the northern part of the Kildonan district. Pegmatites and aplites form veins and irregular bodies which seem to replace the country-rock. There is never any sign of chilling. Quartz, felspar, and muscovite are the most important constituents of the leucocratic veins. Garnet, biotite, and fibrolite occur locally. A few aplites contain fibrolitic knots which only differ from the faserkiesel of the granulites in the abundance of muscovite.

Threads of a green rock, composed in varying proportions of quartz, fibrolite, muscovite, and garnet, penetrate many leucocratic

veins in districts where the country-rock contains fibrolite. These threads, which often run in parallel groups an inch or so across, have a characteristic greenish translucent or silky surface. They have been grouped, together with similar veins in the country-rock, under the name of " green veins ".

A green vein often follows a winding course down the centre of a small pegmatite, and may continue alone through the country-rock when the pegmatitic shell has thinned away to nothing. In larger pegmatites the green veins may cluster into a knot a few inches across.

Fibrolite is also found at the edges of leucocratic veins and quartz lenses. The mineral is often mixed with quartz, and forms a dense white selvedge studded with red garnets. White streaks of the same material occur inside the veins, and probably represent flakes of altered country-rock.

Some green veins are not connected with pegmatites or aplites, but occur independently in fibrolite-bearing country-rock. In the Cnoc na Beiste granulites a green vein may break up into a string of faserkiesel knots.

Petrography

A. *Pelitic Rocks*

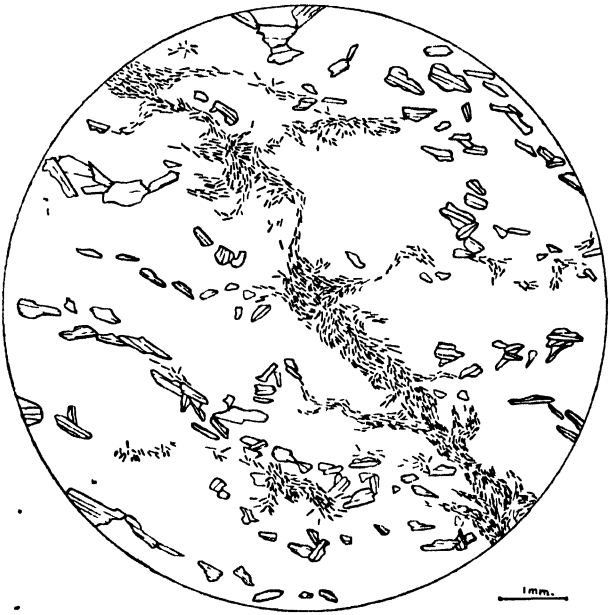
The rocks near Suisgill Lodge are coarse wavy-foliated schists with garnet and muscovite. There is little or no fibrolite.

The central and northern part of the Suisgill belt has been strongly affected by injection-metamorphism. The rocks are coarse poorly foliated gneisses containing irregular flakes and lenses of quartz and felspar. Muscovite is less common than in the schists. Fibrolite is abundant. In section these gneisses show an alternation of light and dark bands, occasionally distorted by oligoclase porphyroblasts. In the dark bands, reddish biotite, partly replaced by muscovite, is the dominant mineral. A patchy alteration to fibrolite has taken place. The fibrolite occurs either as tiny needles inside the mica or as a fringe around the flakes. Some biotites have only a few parasitic tufts upon them, while others are reduced to vague, but still pleochroic, relics surrounded by a confused growth of fibrolite containing grains of iron ore. Total destruction of the biotite results in the formation of a silky grey mat of fibrolite, up to half an inch long and visible in the hand specimen. Fibrolitization is most intense along definite planes in the rock. In the most highly permeated gneisses, which otherwise contain only a little fibrolite, the mineral is often present around the granitic lenses. Bundles of fresh-looking fibres project into the new quartz and felspar. The light bands of the gneiss consist of grains of quartz and felspar (chiefly oligoclase) with a few partly digested biotites, occasional tufts of fibrolite, and a ragged growth of

replacing muscovite. The twin lamellae of the plagioclase are sometimes bent or broken.

The most highly felspathized gneisses of Learable Hill are almost granitic in composition. In them fibrolite is scarce.

Small veins of fibrolite, or quartz and fibrolite, occur in the gneisses (see Text-fig. 2). The foliation planes are crumpled against them; some of the biotites are bent, but muscovite is never distorted. The vein fibrolite appears as a mass of tiny unorientated fibres in which



TEXT-FIG. 2.—Fibrolite vein in fibrolite gneiss. Biotites lined, quartz and felspar blank. Learable Hill.

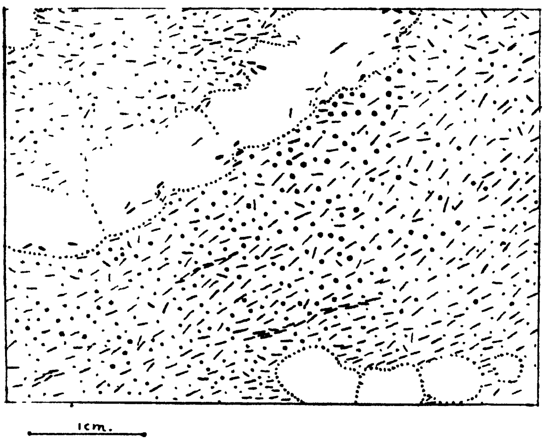
relics of biotite and grains of iron ore are embedded. When fibrolite is mixed with quartz it forms a ropy growth outside the quartz grains. As a vein crosses the micaceous folia of the gneiss it puts out short side branches along them; these replace biotite and are identical with the fibrolite mats belonging to the gneiss. They are indeed continuous with these mats, and the fibrolite appears to be of the same age in both. The rock at the edge of the veins is often impoverished in felspar and enriched in quartz and fibrolite.

B. *Semipelitic Rocks*

The granulites are fine-grained greyish rocks containing occasional coarse recrystallized patches of granitic appearance. In section quartz

forms rounded grains, between which irregular areas of untwinned felspar have developed. Small parallel flakes of dull brown biotite penetrate the mosaic. Ragged muscovite flakes are associated with the felspar and biotite. Rocks of this type occur both outside and inside the injection complex. Within the complex, for example on Cnoc na Beiste, faserkiesel is developed and the groundmass is locally blotted out by thick growths of fibrolite.

The centre of each faserkiesel knot consists of fibrolite with grains of iron oxide. Further out the fibres divide into bunches surrounding grains of quartz. Finally they are reduced to sprays penetrating the granulitic ground-mass and sometimes taking root in a near by biotite flake. At the edges of the knots irregular plates of muscovite form a kind of cement for the fibrolite and quartz. It is not clear whether the muscovite is replacing fibrolite or whether the two minerals are contemporaneous.



TEXT-FIG. 3.—Green vein in faserkiesel granulite. The biotites are shown as short lines, the granulite dotted, and the quartz-fibrolite rock left blank. Cnoc na Beiste.

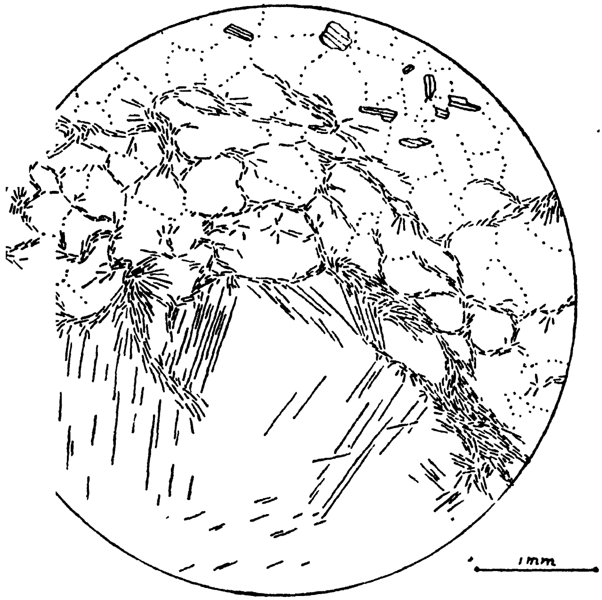
In sections cut parallel with the foliation the fibrolite of the knots has a radial arrangement. Sections at right angles to the foliation show the fibres arranged in a spongy network whose mesh is filled in with quartz and drawn out in the direction of the foliation.

The normal texture of the granulite continues undisturbed up to the edge of the knots. Biotites retained their usual orientation. Micaceous films are not pushed aside by the growth of the fibrolite. They simply disappear and reappear at the other side of the knot. Text-fig. 3 shows a small green vein and a group of knots in biotitic

granulite. The mica flakes are indicated by short lines. The fabric is not distorted around the fibrolitic areas.

Quartz-fibrolite rock occurs also as lumps and streaks, sometimes formed by the coalescence of a group of knots (see Text-fig. 3). In section these areas consist of a streaky network of fibrolite bundles enclosing oval grains of quartz. There are also continuous veins of the same material.

Fibrolite is produced at the contacts of some granite veins. The zone of alteration, half an inch in thickness, contains irregular knots and tufts of fibrolite together with quartz, iron oxide, and relics of



TEXT-FIG. 4.—Development of fibrolite at the edge of a granitic vein (below), in a granulite (above). Quartz and felspar left blank. Cnoc na Beiste.

biotite (see Text-fig. 4). At the actual contact the fibrolite forms a continuous selvedge from which, in some cases, a fringe of slender hairs spreads out into the vein itself, penetrating quartz and felspar indifferently. Text-fig. 4 illustrates the difference in habit of the fibrolite in the country-rock (above) and in the vein (below). The fibrolite in the vein shows a beautiful parallel orientation, which is partly controlled by the orientation of the host grains, and partly by the attitude of the wall of the vein. A whole group of fibres may change its direction of growth. In general the fibres grow at right angles to the wall on which they are based ; and adjacent groups, whose bases

are set at an angle, may actually meet or cross each other. These facts show that the parallelism of the fibres is here controlled from within, and is not the result of external pressure.

Colourless fibres of muscovite often appear instead of fibrolite, or form the outer part of a fibrolitic knot. Such fibrous muscovite passes into ordinary flaky muscovite. It may be replacing the fibrolite.

Semipelitic granulites surrounding areas with fibrolite are usually impoverished in felspar.

The veins which have fibrolitic selvedges are so thin that they cannot be supposed to have had any thermal effect on the country-rock. The alteration that they produce is probably due to the metasomatic activity of the solutions they carry. Some of these solutions escape through the walls of the vein and transform the country-rock to fibrolite. The rest proceed further along the plane of weakness followed by the pegmatite and there form a green vein. Thin pegmatites are often seen to pass into green veins.

C. *Veins of the Complex*

The veins penetrating the country-rock can be divided into two groups, of which the second is slightly younger than the first :—

1. Leucocratic granites, pegmatites, and aplites.
2. Fibrolite-bearing veins.

Group 1 is of regional importance, and veins of this sort occur everywhere in the Strath Halladale Complex. Group 2 includes the " green veins " whose field relations have already been described. They are present in the Kildonan region, and wherever they occur the country-rock is found to contain fibrolite.

1. *Leucocratic Veins.*

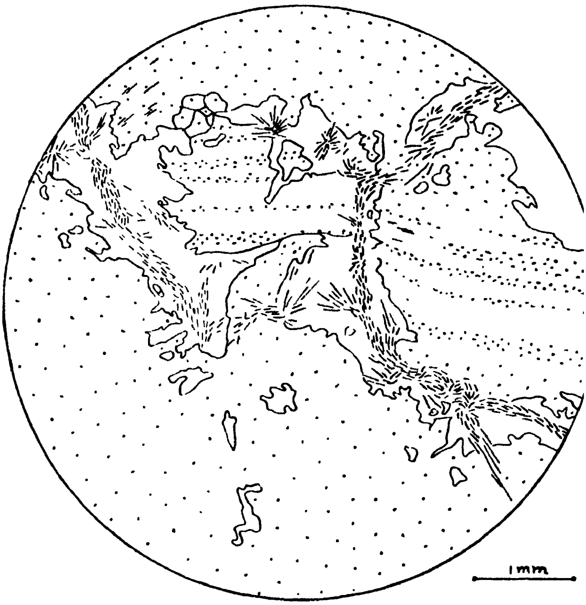
This group is very variable, and a single vein may contain representatives of all three types. Biotitic *schlieren* occur in many exposures. Some aplites are speckled with small red garnets. The only other common accessories are sphene, apatite, and fibrolite.

2. *Fibrolite-bearing Veins.*

The only veins of this type which remain to be described are those which occur in, or emanate from, pegmatites or aplites. They show considerable variety of habit, but all apparently agree in being of replacement origin.

The host rock of one specimen (Text-fig. 5) is a pegmatite. Large subrectangular grains of oligoclase, in which the twin lamellae are sometimes bent or broken, perthite, and quartz are present. The quartz sometimes corrodes the felspars ; ragged muscovites penetrate both.

The fibrolite veins form a system of branching threads, each about a millimetre thick, winding between and through the large felspars. Each vein has a zoned structure. The central part contains only fibrolite. The second zone is composed of irregular bunches of fibrous muscovite. The outermost zone is formed by narrow grains of quartz which corrode and replace the felspars that make the wall. In Text-fig. 5 fibrolite and fibrous muscovite are both represented by short lines,



TEXT-FIG. 5.—Green veins penetrating felspars in a pegmatite. Felspar dotted, quartz blank. Learable Hill.

and the two inner zones have not been distinguished. The quartz of the outer zone puts out blunt-ended processes into the felspar ; these may unite and cut off islands of felspar in which the twin lamellae retain their original orientation. Tufts of fibrolite or muscovite extend into these bays of quartz, and less frequently pierce the quartz and enter the felspar. As with all the rocks described here fibrolite and felspar seem reluctant to come into contact with one another. The veins usually follow the outlines of the felspars. Some pass across the grains, but they do not seem to be filling cracks, for they may end blindly and bluntly in the middle of an undistorted crystal. They can only have been formed by replacement of the felspar substance. Potash-felspar and plagioclase are replaced with equal readiness.

In specimens where the host is finer-grained the veins run in parallel

groups without regard to the pattern of the minerals. The same zoning of the veins, and the same corrosion and replacement of felspar by quartz, is visible. When the veins are closely spaced the host rock between them is entirely devoid of felspar. When they are further apart relics of felspar occur inside the quartz grains of the host. In some pegmatites the thread-like green veins radiate from a larger area where the normal structures of the host have been entirely destroyed. Within this area fibrolite forms radial aggregates, partly replaced by stellate muscovite plates. The felspars of the pegmatite are represented only by rounded fragments inside quartz; a group of fragments, the relics of a single large crystal, may all extinguish together. Fibrolite in these areas sometimes attains an unusually large size and appears in the form of substantial rods arranged in a rectangular or a 60° pattern. Garnets are often extraordinarily common. The trains of fibrolite wind round them.

It may be noted that the vein fibrolite, unlike that of the country-rock, does not contain grains of iron oxide.

Discussion

A. *Age of the Fibrolite*

It is reasonable to assume that all the fibrolite in the sedimentary rocks is of the same age. Faserkiesel knots in the Cnoc na Beiste granulites grade into fibrolite mats in the intercalated pelitic rocks, where the mineral's habit is the same as that found in the Suisgill belt. The vein fibrolite is always closely connected with that in the country-rock. Veins in the gneisses fray out into bunches lying along the foliation, and those in the granulites pass into rows of discrete faser-kiesel knots. The fibrolite in these veins must be contemporaneous with that in the country-rock. The green veins in the pegmatites and aplites are in no way different from those in the sedimentary rocks, and indeed many veins pass from one host to the other. Thus it appears that all the fibrolite of the Kildonan area is of the same generation.

Green veins penetrate and replace the minerals of the pegmatites. When they occur in the country-rock the felspar content of the host is lowered. Part of the fibrolite apparently grew at the expense of felspar. As most of the felspar in the gneisses was introduced during granitization, this puts the growth of fibrolite at a later time than the felspathization. It is also obviously later than the formation of the aplites and pegmatites. Moreover, the movements which fractured felspars in the pegmatites apparently preceded the formation of the green veins, for the latter may pass round or through a bent crystal without themselves showing any sign of disturbance. Of all the important minerals of the rocks fibrolite and muscovite are the only two that are never bent or broken.

It appears therefore that the formation of fibrolite took place at a remarkably late stage in the history of the rocks, when the climax of metamorphism was already well past, and free recrystallization had ceased.

B. *Mineral and Chemical Changes during Injection-Metamorphism*

Pelitic Rocks.—Felspathization is the most important process in these rocks. The growth of fibrolite is a later process which often destroys the felspar in its neighbourhood.

Felspathization involves the addition of Na, Ca, and K. The conversion of biotite to fibrolite demands the removal of Mg, Fe, and K. The displaced iron is to be found in the grains of iron oxide which always accompany the fibrolite of the country-rock.

The changes undergone by the pelitic rocks may be summarized as follows :—

Introduced Na, Ca, K → Felspathization.
(Local movements, cracking and bending felspars.)
Biotite → fibrolite : K, Mg, Fe removed.
Biotite, fibrolite, felspar → muscovite.

Semipelitic Rocks.—Felspathization of the granulites may have taken place, but it is difficult to prove, because it is not accompanied by a change in the appearance of the rock. Most of the semipelitic rocks of the complex have granitic patches which were probably formed at the time of the felspathization of the Suisgill pelitic rocks.

The faserkiesel knots replace the constituents of the granulite without a change of volume and the fabric of the granulite is undisturbed by their growth. It is not possible to explain this reaction in terms of the removal of alkalies, iron, and magnesium from biotite and felspar. It is necessary to assume that the removal of the superfluous elements was balanced by the introduction of either alumina or silica. The ejected iron is represented by grains of iron oxide, and the fringe of muscovite around the knots may account for some of the potash.

Changes in the semipelitic rocks can be represented as follows :—

Introduced Na, Ca.K. → growth of granitic patches
Introduced Al.Si. ——→ growth of faserkiesel : K.Na, Ca.Mg, Fe. removed

According to these suggestions the growth of faserkiesel is the result of two-way migration of material due to metamorphic differentiation or to metasomatic activity. Hinterlechner (1907) and Rüger (1931) consider that faserkiesel knots represent metamorphosed claygalls present in the original sediment. The association of the Kildonan knots with veins of the same material, and the evidence that they replace an originally homogeneous ground-mass, makes such an explanation impossible in this case.

The fibrolite of the pelitic rocks is formed chiefly at the expense of biotite. That in the pegmatites is formed from felspar. Both minerals contribute to the growth of faserkiesel. The mineral changes involved are as follows :—

(1) $2KAlSi_3O_8 = Al_2SiO_5 + 5SiO_2 + K_2O$
(2) Biotite $\rightarrow$ Fibrolite + iron oxide + quartz + K_2O + MgO + H_2O

Quartz is a by-product of both reactions and its constant association with fibrolite in the green veins and in the faserkiesel is thus explained. The potash that is liberated may contribute to the formation of muscovite. White mica is, however, such a common late mineral in granites and gneisses that its appearance may have nothing to do with the reactions discussed here.

In the absence of chemical analyses it is impossible to decide whether the fibrolite-bearing members of the complex are enriched in alumina as a whole, or whether the alumina necessary for the growth of fibrolite has been provided by rearrangement of material within the rocks concerned—in other words, by metamorphic differentiation.

The close association of the leucocratic veins of the complex with fibrolitized rocks suggests that these veins were the channels through which the metasomatizing fluids were introduced. Read (1931, p. 163) was of the opinion that the introduced material was native to the pegmatitic juices, and was not the result of contamination : " . . . These sillimanite-bearing granites have none of the characters of mixed or contaminated rocks which are invariably . . . surmicacé. . . . The sillimanite and replacing or late muscovite . . . are genetically connected and both, most likely, arise by the break-up of aluminium halides, alkali aluminates, and similar compounds contained in the residual portions of the granitic magma . . . the operation of similar solutions in the formation of certain types of sillimanite-bearing country rocks, such as faserkiesel rocks, is not impossible."

D. *Origin of Fibrolite*

The fibrolite of Kildonan was produced at a late stage of migmatization under the influence of migrating solutions which were set in motion by the formation of the leucocratic veins of the complex. Thus, although the mineral occurs in metamorphic rocks, it was a metasomatic product of granitization. In this case at least, it would be undesirable to use the mineral as an index of the grade of regional metamorphism.

The association of sillimanite with the late juices of granites and migmatites is well known. Uncontaminated sillimanite-bearing pegmatites have been described by Anderson (1928), Beverley (1934), and Pegau (1932). Chatterjee (1932) considered some of the sillimanite segregations in the basement complex of India to be of pneumatolytic

origin. Sillimanite selvedges to veins connected with granites have been described by Williams (1934) and Hinterlechner (1907). " Nodular granites," containing large knots of sillimanite, muscovite, quartz, and often tourmaline, are known from several localities. Adams and Barlow (1910) ascribe the knots of a Canadian example to the differentiation of an aluminous fraction from a granitic magma. Sederholm (1928) attributes the production of Finnish nodular granites to the contact action of a later granite. Bugge (1945) considers the knots in a Norwegian granite to be armoured relics which were formed in pelitic schists before granitization and survived because they were protected by the growth of a skin of muscovite.

There is thus ample evidence that sillimanite can occur as a constituent of pegmatites and granites. The status of the mineral in other areas of regional metamorphism, and in contact aureoles, cannot be determined without further study, but it is clear that sillimanite is not formed only as a result of changes in the physical conditions of metamorphism.

In conclusion I should like to thank Professor H. H. Read for suggesting the problem for investigation and Professor Read and Dr. R. M. Shackleton for their help and advice during the course of the work.

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Twelve Years' Measurement of Accretion on Norfolk Salt Marshes

By J. A. STEERS

IN this magazine for January, 1938, there appeared a short note on the rate of sedimentation in the salt marshes of Scolt Head Island. The records then only covered two years. In a note in the *Trans. Norfolk and Norwich Nat. Soc.*, 15, 1939, 41, some additional readings, covering four years, were published and analysed. This summer (June, 1947) I was able to measure the accretion again after a further interval of eight years, so that we now have rates and averages for two, four, and eight years. Unfortunately the line on Aster Marsh was partly destroyed during the war when it regrettably formed part of the target area for artillery fire.

There is no need in this note to recapitulate the ecological facts enumerated in 1938. The vegetation is locally thicker, and the marshes have increased noticeably in height, but for all practical purposes the description of the marshes as printed in 1938 holds good to-day.

In 1937 and 1939 a bicycle pump pushed into the marsh and withdrawn with a small core of sediment was found adequate. This year, now that accretion has often exceeded eight centimetres, it was found that the compression in the pump was too great, so that the sediment stations had to be dug carefully with a sharp spade.

During the war years several stakes originally marking the stations were removed, so it was often difficult to find the exact spot. Because of this some patches of sand have been damaged and may be of rather questionable value for future measurements.

The more important facts shown by the measurements made in 1939 and 1947 are :—

(1) The rate of accretion is usually highest on the lowest marshes, provided that there is always sufficient vegetation to prevent the sand being washed away.

(2) The greatest amount of accretion is usually near big creeks : this depends first on there being sufficient vegetation to trap the silt, and secondly, and perhaps more important especially in the older marshes, on a thick spread of *Obione* along the creek banks.

(3) The Golf Links Marsh has a much narrower entrance than any other investigated. It seems likely that sedimentation is more rapid for this reason, but an exact parallel is impossible since it was quite impracticable to tie this marsh to the others by a careful line of levels.

(4) The Lower Hut Marsh line shows that, on the whole, accretion is fairly uniform throughout : there were two exceptions in 1939,

stations 1 and 6. Unfortunately the lateral erosion of the creeks on either side of station 6 has now (1947) completely destroyed it.

(5) The long line on Missel Marsh also demonstrates reasonably uniform accretion. Station No. 10, near a major creek, has throughout the whole experiment shown a very rapid rise in level.

(6) The Upper Hut Marsh line is a little higher than the others. Correspondingly it shows a lesser amount of accretion, but a fairly close relationship exists between the amount of sedimentation and distance from the main creek.

Slight and perhaps significant differences were reflected in the sedimentation on all lines (including that on Aster Marsh) in the twenty-one months before June, 1937, and the twenty-four months after that date. On Lower Hut Marsh, with the exception of Station 6, the amounts during the second period were rather less than in the first. On Missel Marsh, apart from minor exceptions, the converse of this was true. On the Golf Links Marsh the amounts were generally higher during the second period. No reliable inferences could be drawn from the line on Upper Hut Marsh.

Leaving aside the rather doubtful exception of the line on Upper Hut Marsh, the total amount of accretion tended to fall on the higher marshes and increase on the lower and enclosed marshes. These conclusions were based on a period of barely four years, and are clearly insufficient for reaching any very significant conclusion. Nevertheless they showed first that the rate of sedimentation is slow until a marsh is covered with a fairly thick cover of vegetation and has already gathered a spread of mud on it, and second, that after a marsh attains a certain height, the amount of tidal flooding falls off, and continues so to do as the marsh rises higher. This is naturally reflected in the rate of sedimentation, and so it follows that there is a period of some length during which the most rapid growth occurs. Missel Marsh seems to be near the end of this phase.

If we consider the facts and figures obtained this year, it will be seen that the conclusions reached in 1939 are, on the whole, substantiated. For the most part (see table) sedimentation is highest near creeks, but this conclusion is least noticeable on Lower Hut Marsh. The average rates of sedimentation along each line for the 45 months ending 1939 and for the 141 months ending June, 1947, are :—

	1939.	1947.	
	cm.	*cm.*	*cm.*
Missel Marsh	*c.* 3·33	10·6	3·38
Lower Hut Marsh	*c.* 2·67	7·5	2·39
Golf Links Marsh	*c.* 2·16	6·40	2·04
Upper Hut Marsh	*c.* 0·81	2·80	0·90
Aster Marsh (Long Line)	*c.* 1·74	5·25 (for 7 lower stations)	1·67

These figures are closely comparable. If we divide the 1947 figures by 3·13 we have a direct relationship with the 1939 figures : the results are given in the last column of the table. It is clear from these that on Lower Hut Marsh and Golf Links Marsh there is a slight tendency for the rate of accretion to decrease. This is expectable in view of the stage of the development of the vegetation of these two marshes. Missel Marsh is a little lower in level than Lower Hut Marsh and is covered more often by the tide. Thus the very slightly increased rate is normal. A glance at the table shows, however, that as could be expected, with one or two exceptions, the accretion rate at all the lower stations is rather more than at the upper, and we may probably conclude that, on balance, the rate of accretion is steady and will, in a few years, begin to decline. The anomaly is Upper Hut Marsh. Although the increase is small, it seems definite, and because of the height of this marsh relative to tidal inundation one would, prima facie, conclude that the rate should have been less than in the 1935–9 period. The major increases are usually near creeks, and it may well be that the growth of *Obione*, both in trapping silt carried along the creeks and also in holding sand occasionally blown from the dunes, offers a sufficient explanation.

The results obtained from the still unaffected stations on the long line on Aster Marsh are interesting, and indicate once again the importance of distance from a creek in governing the rate and amount of sedimentation. The upper stations, in both lines, had been partly destroyed by shell-fire, or partly buried under sand set free by shells bursting in the adjacent dunes.

Taken as a whole the most satisfying feature is the remarkably close correspondence on all lines between the average rates for the two periods.

Comparative table showing amount of accretion in centimetres on each line in June, 1937, and June, 1947. = between any two stations means that one or more creeks intervene ; N.R. = no record. The table is directly comparable to those published in this Magazine in January, 1938.

Station	Missel Marsh		Lower Hut Marsh		Golf Links Marsh		Upper Hut Marsh		Aster Marsh	
	1937	1947	1937	1947	1937	1947	1937	1947	1937	1947
1	0·20	N.R.	0·70	6·5	0·63	5·0	0·20	2·4	0·80	N.R.
2	1·25	8·5	1·18	7·5	1·45	9·5	0·30	N.R.	0·68	N.R.
3	1·25	7·5	1·42	8·0	1·27	11·0	0·42	2·0	0·68	N.R.
4	1·75	12·5	1·05	7·0	1·02	5·7	0·10	1·4	0·30	3·9
5	1·78	10·8	1·40	8·7	0·76	5·3	0·15	1·2	0·50	2·7

Station	Missel Marsh		Lower Hut Marsh		Golf Links Marsh		Upper Hut Marsh		Aster Marsh	
	1937	1947	1937	1947	1937	1947	1937	1947	1937	1947
6	1·75	9·0	1·50	N.R.	0·76	6·0	0·05	1·5	0·56	2·7
7	1·48	9·4	1·15	7·0	0·61	4·0	0·30	2·5	0·85	5·8
8	1·88	10·6	1·37	7·6	0·65	4·7	0·15	1·0	1·0	6·1
9	1·70	9·4	1·68	8·5			0·05	1·7	0·78	5·2
10	2·50	14·0	1·72	8·4			0·18	3·5	1·60	10·4
11	N.R.	N.R.	1·45	8·0			0·88	4·0	Subsidiary Line N.R. 1947	
12	1·67	10·0	1·80	6·4			0·60	6·0		
13	1·00	N.R.	1·50	6·5			0·83	N.R.		
14	1·72	10·0	1·32	9·0			0·56	N.R.		
15	1·48	10·0	1·50	7·4			0·26	6·8		
16	1·55	11·3	1·40	7·3			0·28	N.R.		
17	1·45	11·5	1·30	6·5			0·40	N.R.		
18	1·60	10·0	1·52	8·8			0·18	3·8		
19	1·68	9·0	1·65	9·0			N.R.	N.R.		
20	1·72	11·0	1·12	5·8			0·0	1·5		
21	1·80	10·5	1·35	6·0			0·0	N.R.		
22	1·63	10·5	1·52	8·5						
23	1·60	11·5	1·12	N.R.						
24	2·05	11·5								
25	2·47	11·0								
26	1·85	9·8								
27	1·68	10·0								
28	1·70	12·0								
29	1·70	11·0								
30	1·95	12·0								
31	1·65	11·0								
32	1·60	10·5								
33	1·50	11·5								
34	1·60	12·5								
35	0·75	10·5								
36	N.R.	N.R.								
37	N.R.	N.R.								

Numerous small runnels and salt pans.

N.B.—The differences in level between Stations numbered 1 on Lower Hut Marsh, Upper Hut Marsh, and Missel Marsh in 1935 were :—

	Feet.
Lower Hut Marsh and Upper Hut Marsh	0·80
Lower Hut Marsh and Missel Marsh	0·52
Upper Hut Marsh and Missel Marsh	1·32

Referred to Ordnance Datum the heights of these Stations were Missel Marsh, 7·84 feet ; Lower Hut Marsh, 8·36 feet ; and Upper Hut Marsh, 9·16 feet.

On Some Bathonian Mollusca from Skye

By TENG-CHIEN YEN [1]

(PLATE XI)

THE present paper is based on material partly from the collection of the Geological Survey of Great Britain and partly from a collection made by myself in May, 1947, at Kilmalaug Bay, North Trotternish, Skye. It is believed that the species of mollusca here reported form the first records from the Bathonian beds exposed there. Tate (1873) did not make any reference to this locality, although the area was marked as " Aird " on the map of the Islands of Skye and Raasay forming plate xi of Bryce's paper (1873), to which Tate's work was an appendix.

The stratigraphical position of the deposits exposed at Kilmalaug Bay is about 180 feet below the base of the Oxford Clay and is in the upper part of the so-called " Great Estuarine Series ". The deposits consist of a bed of sandy limestone about 1 ft. thick, followed in downward succession by a very thin band of black shale of 1½ in., a band of fine-grained cementstone of about 4 in., and a bed of sandy limestone of 1 ft. at the base. The fine-grained cementstone bed contains the following species of gastropods in addition to some undeterminable pelecypods :—

Procerithium cf. *pisoliticum* (Hudleston)
Procerithium cf. *vetustum* (Phillips)

The sandy limestone bed yields a large number of individuals of one species of pelecypod and two species of gastropods, namely—

" *Cyrena* " *jamesoni* Forbes
Bathonella cf. *scotica* (Tate)
Bathonella bithynoides n. sp.

These fossiliferous deposits occur above the " Lower Ostrea Bed ", from which they are separated by several beds of soft sandstone, black shales, ostracod-marl, and sandy shales, amounting in total to a thickness of about 9 feet.

[1] The work was carried on with the support of a grant-in-aid from the Penrose Fund of the Geological Society of America ; to the Administrative Officers of which Society, I express my heartfelt thanks. I must also thank Mr. F. W. Anderson, of the Scottish Office of the British Geological Survey, for his help and co-operation ; without his assistance in the field I should not so readily and conveniently have examined the fossil sites. I also want to thank him for the field information of the fossil locality herein described. My thanks are due to Professor T. N. George, of the Department of Geology of the University of Glasgow, for his valuable suggestions and for the facilities I have been given in his Department. To Dr. L. R. Cox, of British Museum (Natural History), I am much indebted to his kindness in reading over the manuscript and for his valuable suggestions.

The presence of two species of *Procerithium* together with some *Spirorbis*-like forms in the fine-grained cementstone bed indicate clearly that the enclosing rock is of marine origin: the tubular *Spirorbis*-like form of minute size occurs aggregated in masses in the deposit. The molluscan evidence as to the depositional environment of the sandy limestone bed is less certain, however, and the *Cyrena*-like forms in the rock are usually supposed to indicate an estuarine facies.

Descriptions of Molluscan Species

The following species of mollusca are recorded from the above-mentioned beds. Among them one genus and one species are herein described as new, while others are comparable to allied species. All the types and other specimens recorded in the present paper are preserved in the Palaeontological collections of the Geological Survey Museum.

Bathonella, new genus

Shell naticoid, umbilicated, having a more or less acutely conical spire, and a descending, ventricose body whorl. Whorls increasing rapidly in size, strongly and evenly convex and slightly shouldered. Early whorls bearing marked spiral and growth lines, the spiral lines obscurely traceable on the later whorls, and the lines of growth becoming more pronounced and distinctly curved towards the base of the body whorl. Aperture ovate in outline and barely attaching to the preceding whorl, having its peristome continuous, outer lip margin retreating at the base, parietal wall short, and columella gently arched or nearly straight. Umbilicus narrow in the young and well open in the more mature shells.

Genotype: *Paludina scotica* Tate.

This genus is characterized by having an acute angle to the spire, strongly convex whorls, a rapidly dilated body whorl, a laterally descending aperture with continuous peristomal margin, a short parietal wall, and a nearly straight columella. These features in combination produce an entirely different aspect of the shell from that of any species of *Viviparus* hitherto recorded.

The shell outline recalls some forms of *Natica*, but its thin shell substance, and the absence of the umbilical callosity differentiate *Bathonella* from any genus of Naticidae. The general outline of the shell and the simple sculpture are reminiscent of *Recluzia* Petit de la Saussaye, a genus of the recent fauna occurring in warm seas, and this indicates well that a *Viviparus*-like form of shell can be found in the marine fauna.

Judged by the similarity in morphological features and taking into

consideration the geological age, the nearest group related to this new genus may be *Coelostylina* Kittl, a genus recorded from Permian to Jurassic. However, *Bathonella* differs from that genus by its more strongly convex whorls, more rapidly increasing in size, its almost circular peristomal margin, and its straight columella. On morphological resemblance *Bathonella* is for the present assigned to the family Coelostylinidae Cossmann.

The holotype of *Paludina scotica*, as F. W. Anderson has recognized, is an immature specimen. Through his kindness I am able to illustrate the more mature specimens of this species (Pl. XI, fig. 1*a*, *b*, *c*, *d*). There seems to be little doubt that the species resembles very closely *P. langtonensis* Hudleston (Pl. XI, fig. 2*a*, *b*, *c*, and fig. 3), from the Sharp's Hill Beds in North Oxfordshire, and *Viviparus aurelianus* Cossmann from St. Gaultier in Indre, France. The three forms are most probably congeneric, and those from Oxfordshire and Indre may be only varieties or subspecies of *Paludina scotica*.[1]

Whether a constituent of fossil or of recent faunas, there seems to be no doubt that *Viviparus* has always been a genus of true freshwater habitat. Its prolific occurrence in any bed would therefore positively indicate freshwater deposition. Usually it is accompanied by other genera of freshwater mollusca or invertebrates, as in the Morrison beds in North America and the Purbeck in Europe.

Bathonella, however, has nowhere been found in association with fossils of undoubted freshwater origin. In Skye, as already seen, it occurs with *Procerithium*; in North Oxfordshire, Walford (1906, p. 8) states that it occurs with such true marine genera as *Ataphrus* and *Nerinea*; while in Indre the associated genera are *Nerinea*, *Delphinula*, *Emarginula*, and *Patella*. The evidence suggests, therefore, that *Bathonella* was a genus of marine habitat.

Bathonella bithynoides n. sp.

(Pl. XI, fig. 4*a*, *b*, *c*, *d*)

Holotype: Geol. Survey 75538; paratypes, G.S. 75535–7, 75539–47.

Shell ovately oblong in outline, narrowly umbilicated, having an acutely conical spire and a dilated body whorl. Whorls six to eight, rapidly increasing in size, evenly convex and bearing strong lines of growth, which are very wavy towards the base of the body whorl. The sculpture on the early whorls is not traceable. Aperture ovate in outline, descending and barely attaching to the preceding whorl,

[1] I am confirmed in this opinion after an examination of the type of *P. langtonensis*, made available to me for study through the kindness of Mr. A. G. Brighton, of the Sedgwick Museum.

having a continuous peristome ; outer lip retreating below ; parietal wall short and columella gently arched.

	mm.	mm.	mm.	mm.
Altitude of shell .	11·0 +	12·0 +	11·6	11·0
Width of shell . .	7·0	8·6	7·1	7·2
Height of aperture .	6·0	7·0	5·3	5·0
Width of aperture .	5·0	6·0	4·9	4·5

This species differs from *Bathonella scotica* (Tate) in its much smaller size, more oblong outline, higher spire, and narrower umbilicus. The sculpture is poorly preserved on the specimens available, and the apical whorls in most cases are not well preserved. However, its general outline and apertural features seem to justify its reference to *Bathonella*. It differs from the young individuals of *B. scotica* in its more oblong outline and higher spire.

Procerithium cf. *vetustum* (Phillips)

(Pl. XI, fig. 6)

Cerithium vetustum Phillips, Hudleston, 1888, p. 148, pl. 8, figs. 5*a*–6.

A few examples in the collection resemble this species. It is narrowly slender in outline and has over twelve whorls, which are scarcely convex. The sculpture consists of four to five spirals, which are intersected by sparse axial riblets producing constrictions in places, particularly noticeable near the suture. One example measures 12 mm in height and 3·5 mm in its greatest width.

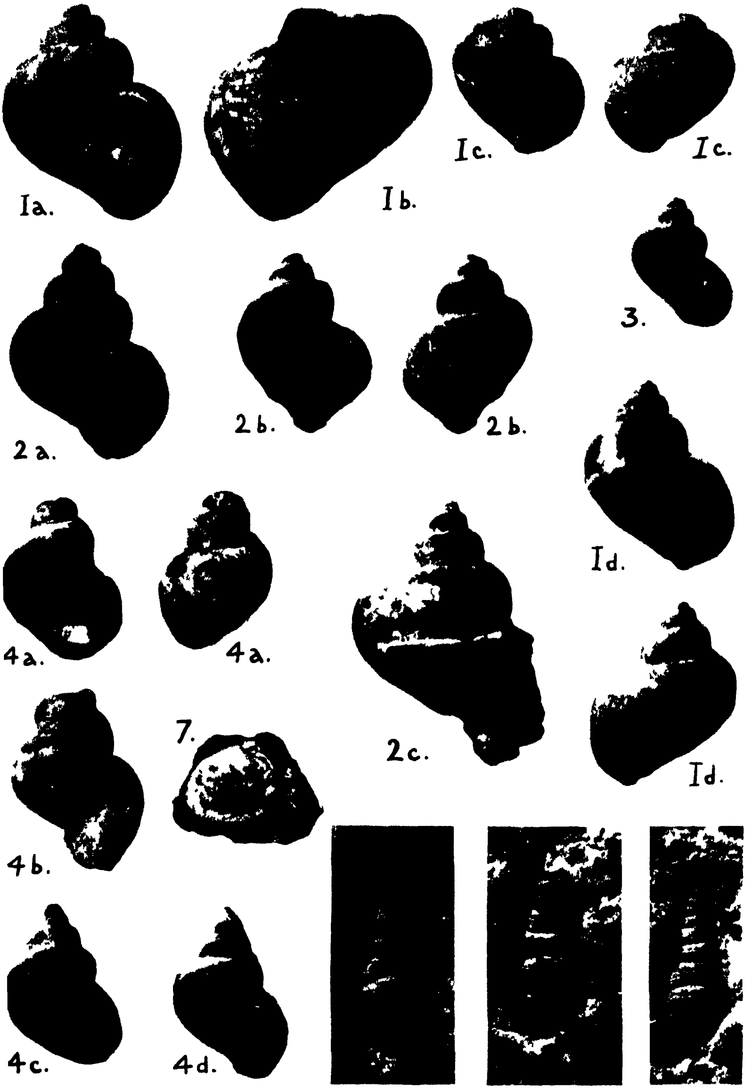
Procerithium cf. *pisoliticum* (Hudleston)

(Pl. XI, fig. 5*a*, *b*)

Cerithium pisoliticum, Hudleston, 1888, p. 164, pl. 9, fig. 13*a*, *b*.

This form is comparatively broad in shell outline, with more strongly convex whorls. The sculpture consists of both spiral and axial lines ; they are fine and closely arranged, producing a granular appearance on the surface. One example measures 12 mm in height of shell and 4·5 mm in its greatest width.

Both these forms of *Procerithium* were found in the thin band of fine-grained cementstone in association with some *Spirorbis*-like form and an undeterminable species of pelecypod. They are represented by several individuals, though most of them are imperfectly preserved. Their general outline, sculpture, short anterior notch, and columellar callosity seem to characterize them as forms of *Procerithium*. They may not be conspecific with Hudleston's *pisoliticum*, but any definite specific status will have to be based on better preserved specimens.



BATHONELLA, PROCERITHIUM, AND " CYRENA."

" *Cyrena* " *jamesoni* Forbes
(Pl. XI, fig. 7)

Cyrena jamesoni, Forbes, 1851, p. 111, pl. 15, figs. 7–8.

On the basis of the external form and size I provisionally assign these specimens to this species, which was described from the " estuarine shales " at Loch Staffin in Skye.

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EXPLANATION OF PLATE

FIG. 1*a*, *b*, *c*, *d*.—*Bathonella scotica* (Tate). Specimens collected by F. W. Anderson from greenish grey shelly shales at about 270 feet above the top of the Inferior Oolite Series near Lealt River, Inver Tote, Skye. Fig. *a*, an adult specimen (altitude 29·6 + mm, width 24·4 mm, last four whorls), Geol. Survey Scotland, No. V 1017*c* ; Fig. *b*, a body whorl of an adult specimen (width, 31 mm), No. V 1016*c* ; Fig. *c*, a young specimen (altitude 9·6 + mm, width, 9·4 mm, last three whorls), × 2, No. V 1034*c* ; Fig. *d*, a young specimen (altitude, 25·2 mm, width, 18·5 mm, 4½ whorls), No. V 1024*c*.

FIG. 2*a*, *b*, *c*.—*Bathonella scotica langtonensis* (Hudleston). Specimens from the Sharp's Hill Beds at Sharp's Hill, near Hook Norton, Oxfordshire. Fig. *a*, an adult specimen (altitude, 28·5 + mm, width, 21 mm, five whorls), G.S.M. No. Zd 3368 ; Fig. *b*, another adult specimen (altitude, 23·8 + mm. width 18·6 mm, last four whorls), G.S.M. No. Zd 3369 ; Fig. *c*, an imperfect adult specimen with its first four whorls preserved, × 2, G.S.M. No. Zd 3370.

FIG. 3.—*Bathonella scotica langtonensis* (Hudleston). Specimen from the Neaeran Beds at Castle-Barn Quarry, near Chipping Norton, Oxfordshire. A variety of the form (altitude, 18·6 + mm, width, 12·8 mm, last four whorls), G.S.M. No. Zd 3410.

FIG. 4*a*, *b*, *c*, *d*.—*Bathonella bithynoides* n. sp. Specimens from a sandy limestone bed about 180 feet below the base of the Oxford Clay at Kilmalaug Bay, North Trotternish, Skye. × 2, Holotype G.S.M. No. 75538.

FIG. 5*a*, *b*.—*Procerithium* cf. *pisoliticum* (Hudleston). Specimens from a fine-grained cementstone bed about 180 feet below the base of the Oxford Clay at Kilmalaug Bay, North Trotternish, Skye. × 2, G.S.M. No. 75551.

FIG. 6.—*Procerithium* cf. *vetustum* (Phillips). Same as the preceding species. × 2, G.S.M. No. 75551.

FIG. 7.—" *Cyrena* " *jamesoni* Forbes. Same as *Bathonella bithynoides*. × 2, G.S.M. No. 75548.

CORRESPONDENCE

PRESENT-DAY VOLCANICITY AND CLIMATIC CHANGE

SIR,—It is claimed by some writers (e.g. Humphries, 1913, and Fuchs, 1947) that volcanic eruptions can affect the amount of the sun's radiation received by the earth's surface. According to Humphries, single explosions of modern volcanoes can affect the sun's radiation throughout the world for periods of two to three years ; Fuchs bases a theoretical explanation of Pleistocene climatic oscillations on the assumption that large-scale volcanic activity spread over a long period may be sufficient to cause a marked lowering of the world's temperatures.

Because of the great importance of the implications that may be drawn from these statements, it seems advisable to study the immediate effect of modern volcanic eruptions over world temperatures in the light of the more complete climatic records now available. Thanks to Clayton (1944) there is now a comprehensive body of world weather records made easily accessible, and an enormous mass of detailed material of a more localized nature has become available.

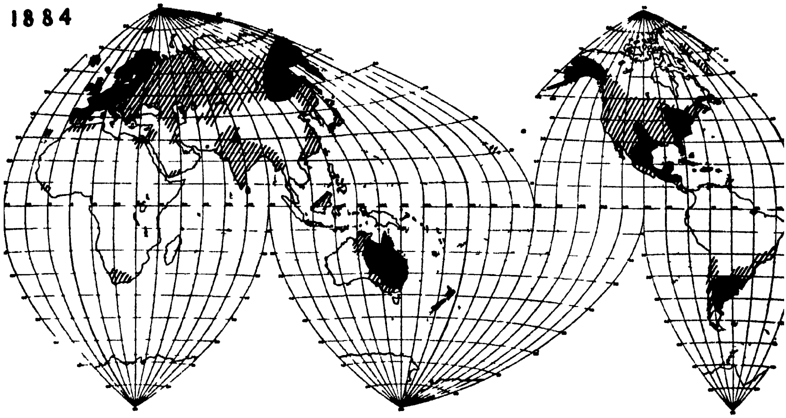
The three outstanding volcanic eruptions of recent years were selected for special study : they were the eruption of the Krakatoa in 1883, that of Katmai in 1912, and that of the Southern Andes in 1921.

It takes a very short time for the erupted dust to reach fairly high regions of the atmosphere. It is assumed that it takes a longer time for this dust to spread over large areas, where alone its blanketing power would be of world-wide importance. For this reason the immediate approach to the problem was made by considering world temperatures in the year following the eruption. The analysis was simplified by grouping together all the records which showed temperatures below the average for the year, and all the records which showed temperatures above the average.

Text-fig. 1 shows the state of our knowledge of world temperatures for the year 1884, following the great explosion of Krakatoa. Most of Western and Central Europe actually experienced temperatures above the average, and so did North-Eastern Asia, the better known part of Alaska, and a section of the Eastern United States. In the Southern Hemisphere, Eastern Australia and most of Argentina were also warmer than usual during that year. Russia, Siberia, India, China, Canada, and most of the United States were cooler than average. So were Chile, parts of Australia, and Cape Province. Perth, W.A., recorded exactly the average temperature for the year.

Judging by area alone it may be said that the area having temperatures below average in 1884 was greater than the area having temperatures above average. But is this fact significant ?

1884



TEXT-FIG. 1 —Regions with temperatures above average (black) and below average (shaded) in the year following that of the Krakatoa explosion

One may study the records of the chief stations showing temperatures *below* average in 1884. The following table gives the deviations from the mean temperature in the few years preceding and following the great explosion. The temperatures are expressed in ° C.

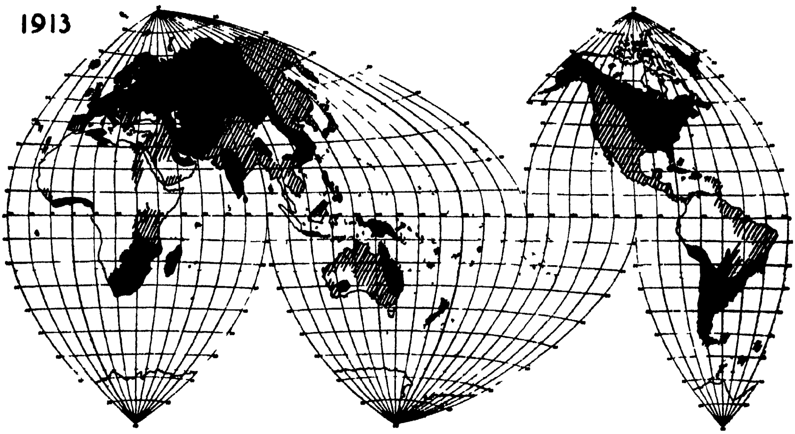
	1881.	1882.	*1883.*	1884.	1885.	1886.
Lisbon . .	+ ·50	− ·46	− ·95	− ·36	− ·77	− ·31
Madrid	+ ·7	+ ·2	− ·5	− ·5	− ·7	− ·2
Rome .	+ ·1	+ ·3	− ·5	− ·6	+ ·4	+ ·3
Hvar .	− ·12	+ ·48	− ·40	− ·49	+ ·23	+ ·25
Bucharest	− 1·7	0	− ·7	− 1·1	− ·4	− ·3
Odessa . .	− 1·5	+ ·7	− ·5	− ·3	+ ·3	+ ·6
Moscow .	− ·9	+ 1·2	+ ·3	− ·7	0	+ ·1
Kazan .	− ·8	+ ·4	+ ·5	− ·8	− ·5	− ·5
Perm . .	—	—	+ ·5	− ·5	− ·5	− ·1
Tashkent .	—	− ·6	− ·5	− ·2	− ·1	− 1·2
Irkutsk .	—	+ ·3	+ ·1	− ·3	− ·1	+ ·5

Farther east one reaches the zone where 1884 brought temperatures above normal. It is clear that the wave of temperatures below normal had already begun in 1883 in Southern Europe, and could not possibly be due to an eruption taking place in the same year thousands of miles farther east.

North American temperature records are given below in ° F. as deviations from the normal.

	1881.	1882.	*1883.*	1884.	1885.	1886.
Sitka	—	− ·4	+ ·7	+ ·6	+ 2·4	+ 1·1
San Francisco . .	+ ·1	− 1·3	− 1·0	+ ·1	+ 1·2	+ ·6
Salt Lake City .	+ ·3	− 2·3	− ·8	− ·7	+ ·8	0
Omaha . . .	− ·5	+ 1·3	− 2·4	− 1·8	− 2·2	− 2·0
St. Paul . . .	+ 1·2	+ 1·7	− 3·1	− ·2	− 1·9	− 1·4
St. Louis . .	+ ·2	− ·2	− 2·2	− ·5	− 1·2	− 2·7
Chicago . . .	+ ·8	+ 1·1	− 2·2	− ·3	− 2·1	+ ·4
Detroit . . .	+ 3·0	+ 3·0	− ·5	+ 1·5	− 1·3	+ ·7

The series could be continued with records for localities farther east and south which had 1884 temperatures near or above the normal. The cool period began in 1882 in the north-west, and in 1883 on the Great Plains and farther east. But it must be stressed that any series of meteorological records shows variations above or below the average. Cool years were experienced from 1873 to 1876, from 1883 to 1888, from 1891 to 1893 in Omaha, the locality which would best bear out the " cooling from volcanic dust " theory according to the table given



TEXT-FIG. 2 —Regions with temperatures above average (black) and below average (shaded) in the year following that of the Katmai eruption.

above. New York, for instance, had cool periods in the same years as Omaha, and in addition from 1895 to 1900. But localities in other countries had warm periods during the same years, or alternate warm and cool periods : Scandinavian records could be quoted as an example.

It may be said that records for the years immediately following 1883 are not very numerous, and not always complete. It is desirable to study world temperatures after the Katmai eruption of 1912, and Text-fig. 2 has been constructed for this purpose. It shows that during that year a larger area had temperatures above normal (black) than below (shaded).

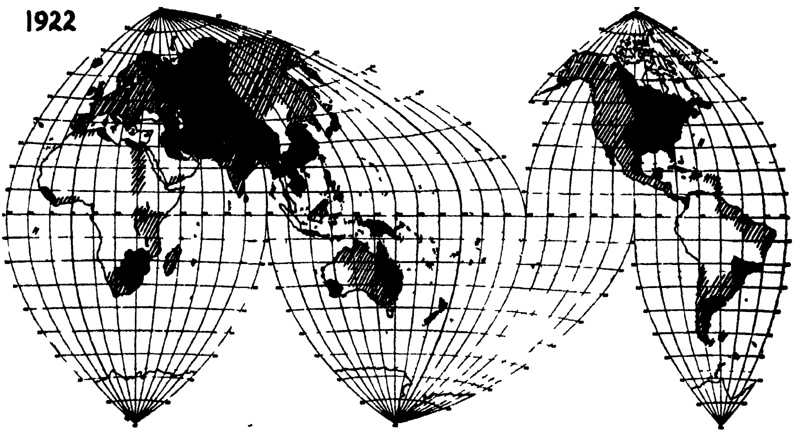
It is unnecessary to give a table for the years preceding and following the 1912 eruption, as was done for those preceding and following the 1883 one : the mass of data used in compiling the map hardly requires any further elaboration. But a more convincing proof could come from an analysis of temperature records for Alaskan stations, which should have immediately felt the effect of the volcanic dust if such effect had been noticeable.

	1912.	1913.	1914.	1915.	1916.
Dutch Harbour	− ·4	+ ·4	+ 2·0	—	− ·7
Eagle	+ 3·9	− ·5	+ 2·6	+ 3·4	+ ·4
Juneau	+ 2·3	+ ·7	− ·5	+ 2·5	− ·3
Nome	+ 4·4	+ 2·9	+ 3·6	—	—
Sitka	+ 1·9	+ 1·0	+ 1·6	+ 3·5	− ·9
Tanana	+ 4·5	+ ·2	+ 3·1	+ 2·5	− ·3
Valdez	+ 2·4	− ·8	+ ·3	+ 1·0	− 1·2

It must in fairness be pointed out that 1913 was a cooler year than 1912 and 1914, but even so temperatures did not fall below normal except at Eagle and Valdez.

Text-fig. 3, constructed for the year following the Andean eruption of 1921, also fails to show any substantial cooling of the earth's surface for that year.

Summing up, it may be said that there appears to be no climatological evidence to support the theory that volcanic eruptions may cause



TEXT-FIG 3 —Regions with temperatures above average (black) and below average (shaded) in the year following that of the Andean eruption.

a lowering of temperatures even in the year immediately following the eruptions and even in regions very near to the erupting volcano. Until more convincing evidence is assembled and produced any attempt to extrapolate to Pleistocene or other periods seems very risky.

J. GENTILLI.

UNIVERSITY OF WESTERN AUSTRALIA.
23rd February, 1948.

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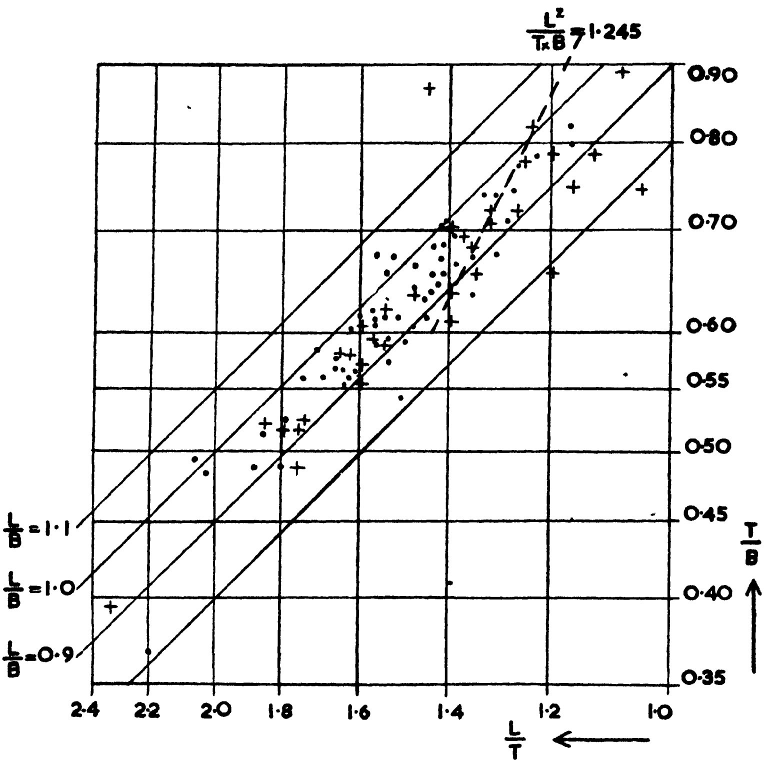
RHYNCHONELLA BOUETI

SIR,—It was with considerable interest that I read W. G. Aitken and W. S. McKerrow's paper (*Geol. Mag.*, lxxxv, 1948, 19–32) on the variation of the rhynchonellids from the Boueti Bed at Langton Herring. Such " Variation Studies " are, of course, of great importance in dealing with the Coal Measure lamellibranchs, and the authors are to be congratulated on applying the technique to another group of fossils.

During a visit to the Dorset coast by the Geological Society's 1947 Students' Tour under the direction of Mr. P. C. Sylvester-Bradley and Dr. W. D. Evans, Mr. R. H. Hoare collected a similar set of



Scatter diagram connecting $\frac{L}{T}$, $\frac{T}{B}$, and $\frac{L}{B}$ for a community of rhynchonellids from the Boueti Bed, Langton Herring.

● = shells collected by W. G. Aitken and W. S. McKerrow. (See Text-fig. 10, p. 29.)

+ = shells collected by R. H. Hoare.

rhynchonellids from the same locality. These specimens, too, fit exactly the variation series recognized by the authors ; this confirms that their collection is, on the basis of the external characters of the shells, fully representative of the rhynchonellid community of that locality.

The authors' text-fig. 10 is indeed a valuable diagram for there is a close correspondence between it and the variation diagram obtained by a subjective analysis of the shells ; but the statement on page 26 that : " The position of each point [in text-fig. 10] thus depends on the relative values of the thickness [T], length [L], and breadth [B] of the shell," may be queried. The present writer would point out that the position of each point in the diagram depends only qualitatively on the relative values of L, T, and B. Quantitatively the points are determined by the relative values of the *ratios* L/T, T/B, and L/B.

Palaeontologically, L, T, and B are " independent variables ", but when the values of L/T (= x say), and T/B (= y), and L/B are plotted it is these *ratios* that, strictly speaking, are the variables. Since these three ratios are connected by the expression $L/T \times T/B = L/B$, only two of them are " independent " variables. Thus text-fig. 10 actually shows only the relation between two independent variables. In other words each point in the diagram is defined precisely by the values of L/T and T/B, the value of L/B being determined automatically in accordance with the expression $L/T \times T/B = L/B$ as given above.

Consequently the same " scatter pattern " as in text-fig. 10 can be obtained by plotting L/T and T/B along ordinary x and y axes. If such a plot is made on an arithmetic scale the pattern differs slightly and the line $L^2/T \times B = 1{\cdot}245$ is a curve, the equation to which is $y = 1{\cdot}245\ x^{-2}$. When, however, the plot is made on a logarithmic scale, as is done by the authors, this line becomes rectilinear and the scatter pattern obtained is that of text-fig. 10.

In this way the complications involved in representing graphically the variation in this community of rhynchonellids are avoided. The diagram enclosed shows the results of such a plot ; also shown on this diagram are the values for some of the shells collected independently from the same locality by R. H. Hoare.

ROBERT K. BLUNDELL.

DEPARTMENT OF GEOLOGY,
UNIVERSITY COLLEGE,
NEWPORT ROAD,
CARDIFF.

8th March, 1948.

SIR,—While not wishing to criticize an excellent piece of work on the rhynchonellids of the Boueti Bed in your January number by Messrs. Aitken and McKerrow (with whom I have unfortunately lost contact since accompanying them on the field party on which the material in question was collected), I do feel that some additional information would greatly increase the value of the paper.

The term community implies a strictly contemporaneous existence in a very restricted locality and the palaeontologist who uses it is making a very exacting claim for his work. The material from a random collection from the shore at Langdon Herring does not at first sight appear to constitute a community, though it might approximate to one if *R. boueti* is substantially absent from the other strata associated with the Boueti Bed and if the front on which the material was collected was sufficiently restricted.

It would be very interesting if this " community " can be established to know, too, something about the lithology and associated fauna, since a community is in complete ecological equilibrium ; that is to say equilibrium with its physical and biological environment. Is there any chance of mixing of forms from a different environment by sampling or by transportation at the time of deposition ? Do, for example, separate, worn, or broken valves occur and do the Polyzoa throw any light upon the environment ? It is again emphasized that in the opinion of the writer the paper remains of great value for its method of treatment and this letter is merely a request that the authors " give us more ". The results obtained would seem to be of much greater interest if they could be augmented by palaeoecological data as well.

F. W. BEALES.

McMASTER UNIVERSITY, CANADA.
12th March, 1948.

CAUSES OF ICE AGE

SIR,—Geologists and others who concern themselves with past climates, and particularly with those of Pleistocene times, have reason to be indebted to Dr. Fuchs and Mr. Paterson for their illuminating contribution to the vexed problem of the inception and development of an ice age, and for the sound contention that the Glacial Period has no single cause, but resulted from a combination of circumstances which could hardly have arisen except during a period of orogeny (Fuchs and Paterson, 1947).

That no one factor is alone responsible for the advent of the great glaciations that have punctuated the geological record has long been recognized ; and Brooks, while stressing the importance of con-

tinentality, writes : " The greatest extremes of climate are not to be attributed to the normal development of one factor, but to the co-operation of a number of different factors acting in the same direction " (Brooks, C.E.P., 1926).

Thirteen years ago I called attention to the necessity of a multiple hypothesis in this regard in a postscript to my presidential address to the Uganda Society (Wayland, 1935). After some remarks concerning Milankovitch's work on the solar radiation curve, which had just reached me, I wrote :—

> Granting the figures . . . and the correctness of the interpretation of the glacial succession in Europe, the curve deduced from the former is found to fit the latter astonishingly well, and thus, on the face of things, it would seem that here we have a complete explanation of glacial and interglacial periods ; but it cannot be claimed that any explanation of the Great Ice Age is thereby given.
>
> Milankovitch's hypothesis is on trial ; but if we assume for purposes of discussion that it is correct, it modifies Simpson's hypothesis in so far as variations of glacial climate are concerned, and thereby rids it of what is to my mind the unfortunate necessity of duplicating the curve within a time-span that seems hardly suited to the general hypothesis ; and by bringing in Brooks's theory of continentality we have an explanation not only of glacials and interglacials but of ice ages upon which these fluctuations are superimposed.
>
> Granting tentatively that (as Simpson holds) the sun is a very long period variable star and that evaporation and precipitation will increase on earth with the amount of solar radiation received, it would seem that only those cycles of high radiation which synchronize with periods of high land elevation can produce glaciation, and that it is only during periods of glaciation (ice ages) that Milankovitch's three astronomical factors can function as controls in the variation of glacial climates.
>
> In brief, a case can be made to indicate that ice ages depend for their existence on the coincidence of high land and high solar radiation, and if the sun is a variable star (even though it be one of very long period) such coincidence is almost bound to occur. Given an Ice Age, astronomical factors (such as those employed by Milankovitch in his hypothesis) by their influence on the amounts of solar radiation received by the earth, control variations of glacial climate.
>
> Three things are thus hypothetically explained : (1) the cause of an ice age ; (2) the synchronism of geological revolutions and ice ages ; and (3) the reasons for glacial and interglacial periods as integral parts of an ice age. The validity of this compound hypothesis remains to be proved or disproved.

To this complex Fuchs and Paterson have added some effects of volcanism, clearly an important matter, which although considered before, particularly by Humphries (4), seems to have dropped out of our calculations of late. They also incorporate, rightly I believe,

Paschinger's work on the depression of the snow line to and below the level of maximum snow deposition. These authors lay great stress on the climatic effects of volcanic dust in the atmosphere of Pleistocene times, and make out a good, but, as yet not unassailable, case in favour of phases of more or less world-wide volcanism sufficiently synchronous to have played a significant part in shaping the climatic episodes of the Great Ice Age. The authors' admission, however, that dust-laden atmosphere is by itself insufficient to promote an ice age seems to be supported by the intensity-distribution of the climatic changes and regimes. Presumably the nearer a volcanic centre the more marked the climatic effects should be, but this seems hardly substantiated by the facts. In the Bechuanaland Protectorate, for instance, where at intervals during nearly five years I have been working on the problem of Pleistocene climates, the effects are very marked, although the nearest volcanoes (excepting the small Pretoria salt pan) which might have contributed dust to the atmosphere in former times are some 1,500 miles away. The climatic sequence of the Kalahari parallels that of East Africa on the one hand and that of the Vaal River basin as worked out by Sohnge and Visser (1937) on the other.

The fact that the Pleistocene pluvials of Eastern and Central Africa were ushered in by great earth movements, and accompanying volcanicity, seemed too marked to be entirely coincidental, and it has rendered the disentanglement of events and the apportioning of them to their proper spheres a difficult task in Uganda, from which country conveniently enclosed basins like those of the Kenya Rift valley are absent (except for relatively small crater lakes), and the maximum height of Lake Victoria has depended upon the altitude of its outlet rather that upon the rainfall.

With low lake levels and their oscillations the matter has usually been different, but one must turn to the river valleys for climatic evidence, for clearly high precipitation might easily synchronize with a tectonically controlled low-level Lake Victoria, and if the present outlet at the Ripon Falls were raised, say, by 50 feet, the lake would presumably rise to this level without increase in rainfall, and the fact that, in spite of theoretically reduced evaporation consequent upon a dust-laden atmosphere, rivers have run strongly during the pluvials seems to favour Simpson's hypothesis and to suggest that the dust mantle was shorn of much of its power to influence climate because of the more dynamic effects of solar radiation. In these circumstances the dust mantle might locally reduce the temperature and assist in precipitation of moisture gathered elsewhere and brought in by favourable winds. This, however, is speculation, and at present we are short of facts.

That a volcanic dust mantle hung over much of East Africa (and probably over other parts of the earth when and where volcanicity occurred) in Pleistocene time there can be little doubt ; much of this may have been precipitated by rain, and the high content of almost unweathered volcanic material, particularly tiny sanidine crystals, in the pluvial lake deposits of the Eastern Rift valley, may perhaps be thus explained. It is to be noticed, too, that these fine-grained sediments extend right to the rock escarpments in many places, a fact which argues against an arid or semi-arid climate during the days of this subaqueous deposition..

To summarize : one may say that the time is passed when lack of information permitted one to ascribe a single dominating cause to the ice age. To-day we must speak of causes in this regard. We are, I think, advancing toward a clearer understanding of these, and the resuscitation and restatement of the volcanic contribution is not a retrograde step, but one which, when fully assessed, will further that advance.

E. J. WAYLAND.

GABERONES,
BECHUANALAND PROTECTORATE.
20th March, 1948.

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LONGMYNDIAN STRATIGRAPHY

SIR,—Mr. Challinor's demonstration, in his article in the *Geological Magazine* for March–April, 1948 (p. 107), that, on the evidence of graded bedding, the eastward dipping Eastern Longmyndian rocks in a quarry on Haughmond Hill are right way up is of considerable interest.

His conclusion that " in Haughmond Hill the Eastern Longmyndian both actually and also stratigraphically overlies the Western Longmyndian " by no means necessarily follows, however, and, indeed, would increase rather than otherwise the difficulties of interpretation of Longmyndian stratigraphy.

On Haughmond Hill the " Green Sandstone Group " is in contact with the Western Longmyndian. On the Longmynd the probable equivalent of the " Green Sandstone Group " (the Burway Group) is separated from the Western Longmyndian by three of Charles Lapworth's subdivisions of the Stretton Series, representing six or seven thousand feet of beds. If the Eastern Longmyndian overlies the Western Longmyndian stratigraphically, the absence of these beds on Haughmond Hill must presumably be due to overlap and the Eastern Longmyndian must be unconformable to the Western (the reverse of J. F. Blake's view). A much more likely explanation is that of Callaway (*Quart. Journ. Geol. Soc.*, vol. xlvii, 1891, p. 112) that the green (Eastern Longmyndian) beds of Haughmond Hill are separated from the purple (Western Longmyndian) by a fault. T. C. Cantrill's inability to find evidence for such a fault (Shrewsbury Memoir, p. 43) is understandable, as at the time he mapped Haughmond Hill he was unfamiliar with the succession on the Longmynd.

Mr. Challinor's further inference that in the Longmynd itself the succession is an inverted one seems equally unjustified as far as the Eastern Longmyndian is concerned. Cobbold and Whittard (*Proc. Geol. Assoc.*, vol. xlvi, p. 348) have shown that the Stretton Shales, the easternmost member of the Eastern Longmyndian, pass down eastwards into the Helmeth Grits. Unfortunately the discussion in the Shrewsbury Memoir (pp. 11–12) to which Mr. Challinor refers was written before the appearance of Cobbold and Whittard's paper, a reference to which had to be inserted in proof, and on that account perhaps undue weight was given to the possibility that the Eastern Longmyndian might be inverted on the Longmynd. Other lines of evidence (e.g., the attitude of fracture-cleavage and the position of planes of pene-contemporaneous erosion) confirm that the westward dipping Eastern Longmyndian beds near Church Stretton are not inverted. It is the Western Longmyndian, not the Eastern, which shows signs of inversion near the Longmynd (Shrewsbury Memoir, p. 11 ; see also Whitehead in discussion of Cobbold and Whittard, *op. cit.*, p. 358).

That Eastern Longmyndian rocks dipping eastwards on Haughmond Hill and westwards on the Longmynd should in both cases be right way up, need, of course, cause no surprise. The structure and stratigraphy of the pre-Cambrian rocks of Shropshire still present unsolved problems. Mr. Challinor's new evidence, interesting though it is, does not, by itself, carry us much further towards their solution.

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GEOLOGICAL SURVEY OF GT. BRITAIN,
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EDINBURGH 9.

14th April, 1948.

ANNOUNCEMENT

THE ORDNANCE SURVEY 2½-INCH MAP

Amongst the recommendations of the Departmental Committee set up in 1935 under the chairmanship of the Rt. Hon. the Viscount Davidson to review the styles and scales, and the bringing up to date, of Ordnance Survey maps, was the initiation of an entirely new map series at the scale of 1/25,000 or about 2½ inches to 1 mile. Some 500 sheets of this map, about one-fifth of the projected total, are now published, and it is hoped that the series will be complete in about three years hence. In the areas already covered there are signs of the increasing popularity of this map.

The decision to introduce the map was based upon a considerable weight of evidence that there was too wide a gap between the 1-inch and 6-inch series. It was believed that, in particular, schools and walkers would appreciate its value, but, in addition, the scale is of course very well suited to many technical and administrative uses. This was manifest during the war. The War Office series at this scale, based on the now obsolescent War Office Cassini grid, and somewhat illegible by reason of its straight photographic reduction from the 6-inch Ordnance Survey map, was widely used by local authorities.

The new Provisional Edition of the 2½-inch map which the Ordnance Survey is producing on National Grid sheet lines is a very different affair. " Provisional " means that it is based on the old 6-inch maps to which certain revision material, collected for A.R.P. war-time purposes, has been added ; on the other hand the final edition will be based on the 50-inch resurvey of built-up areas, now in hand in many towns, on the stringent overhaul of the 25-inch plans in rural areas and on surveyed contours. The 2½-inch Provisional sheets are all newly drawn, with conventional signs, symbols, etc., specially designed to suit the scales ; the result is an extremely clear and pleasing map.

The sheets are squares whose sides lie along the 10 kilometre grid lines of the National Grid, and each sheet is known by the 10 km. grid reference of its S.W. corner. The sheet lines are, in fact, represented by the solid grid lines at 10 km. intervals to be found on the face of all modern 1-inch Ordnance Survey maps and by the only grid lines to be shown on the ¼-inch, and on the 10-mile (1/625,000) maps sponsored by the Ministry of Town and Country Planning. These smaller scale maps are therefore in themselves index diagrams for the new map ; the old system used for indexing 6-inch maps county by county does not apply to it.

The 2½-inch map is obtainable in three styles, the fully coloured, the outline, and the administrative areas. In the first the black detail is confined to the outlines of roads and buildings, railways, lettering

and certain conventional signs. Public buildings are also shown in solid black, but all other buildings have a grey filling. Enclosure boundaries, orchard and wood symbols are also shown in grey, which has the effect of merging the less important map features into the background and thus enabling the more important ones to stand out. (Note, however, that the grey features do not occur in certain Lancashire, Cheshire, Cumberland, Westmorland, and East Anglian sheets.) Water and marsh are in blue, and road fillings, contours (at 25 ft. intervals), and sand are in brown.

The Outline Edition is in grey monochrome, an exact replica of the coloured edition except that the features depicted in brown have been omitted. It is printed on specially heavy paper suitable for use in drawing offices. The Administrative Areas Edition consists of the outline edition with a red overprint naming and defining all classes of administrative boundaries down to parishes and wards. It is understood that the Local Government Boundary Commission intend to illustrate their report using the Administrative Areas Edition of the 2½-inch map. The sales of the Administrative Areas Edition covering rural areas have hitherto been small and it may be necessary shortly to consider whether the production of these sheets is justifiable or not.

It is indeed likely that as the series covers more and more of the country it will be found to oust the 6-inch map wherever minor features of topographical detail are required in a compact form. At the moment the following areas are in course of being covered : Greater London ; Edinburgh, Glasgow, Dundee, and Aberdeen ; Plymouth and Dartmoor ; Purbeck, the New Forest, Southampton, and Portsmouth ; the South Coast from Littlehampton to Ramsgate ; South Wales and Bristol ; Gloucester, Oxford, Cambridge, Reading, and Luton ; East Anglia and the Broads ; Birmingham and the Black Country ; Tyneside ; and, perhaps most completely as yet, Lancashire, Yorkshire, and Cheshire. The Director-General of the Ordnance Survey at Chessington, Surrey, is open to inquiry at all times about what sheets are available in the various styles and which sheets are imminent. The maps themselves are, of course, obtainable, like all maps issued by the Department, from booksellers and map agents.

GEOLOGICAL MAGAZINE

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Bathonian Ostracods from the Boueti Bed of Langton Herring, Dorset

By P. C. SYLVESTER-BRADLEY

(PLATES XII–XV)

THE ostracods described in this paper have all been obtained from the *Goniorhynchia boueti* bed, as exposed at the little peninsula known as Herbury (" Herbeyleigh " in some of the older geological literature), near Langton Herring, some five miles to the west of Weymouth. The bed is at sea level at the north-west corner of Herbury, and is there about one foot thick. It is from this point (national grid ref. 30/610810) that the samples were taken for the separation of microfossils. Polyzoans, baby brachiopods, foraminifera, " vertebral " ossicles of ophiuroids, radioles of echinoids and minute gastropods, make up as diverse and interesting an assemblage as that formed by their better known macroscopic contemporaries.

The base of the Boueti Bed is usually taken as the dividing line between Fuller's Earth and Forest Marble. It has been correlated with the Bradford Clay. The richness of the fauna and the encrustation of the larger shells with polyzoa and small oysters suggest that it accumulated over a long period of time during which there was little sedimentation.

Our knowledge of the ostracods is not yet sufficiently wide to work out any acceptable modern classification. The sub-orders of Sars and the superfamilies of Ulrich and Bassler are sufficiently understood, but the various families, particularly of the Cytheracea, are differently interpreted by almost every author. Until the relationship of *Clithrocytheridea* to *Cythere* sensu stricto on the one hand, and to *Cytheridea* sensu stricto on the other is more clearly understood, it seems impossible to diagnose satisfactorily either the Cytheridae or the Cytherideidae. Numerous attempts of both neontologists and palaeontologists to do so have but added to the confusion. In this paper family names are therefore avoided.

In the following descriptions the dimensions are given in millimetres : first length, then height, then width (usually omitted for single valves). The proportions are quoted for length: height: width, with height as the unit.

Order **OSTRACODA** Latreille

Sub-order **Podocopa** Sars

Super-family CYTHERACEA Ulrich and Bassler

Genus Cythereis Jones, 1850

Genolectotype *Cytherina ciliata* Reuss

The genus *Cythereis* is abundant Recent, and in Cretaceous and Tertiary rocks. The outstanding revision of the genus in recent times is that of Triebel (1940) but we still await a full discussion of the true genotype (*C. ciliata*) and its relation to the supposed synonym (*C. ornatissima*). The species described below differs in details of hinge structure from typical representatives of the genus. It is rare in the Boueti Bed, however, and I am unwilling to separate it from *Cythereis* until more adequate material becomes available.

Cythereis cf. fullonica Jones and Sherborn, 1888

Pl. XII, figs. 7–10 ; Pl. XIII, figs. 3 and 9

Cythereis fullonica, Jones and Sherborn, 1888, p. 256, pl. 4, fig. 13.

Description.—The ornament of *C. fullonica* may be analysed as follows :—

(1) The *anterior hinge tubercle* is present on both valves, that of the left being anterior to that of the right. It corresponds in position to the socket of the hinge.

(2) The *eye tubercle* lies immediately below and just behind the anterior hinge tubercle.

(3) An *antero-dorsal complex* consists of a ridge or series of swellings running from the eye tubercle towards the anterior margin.

(3) An *antero-dorsal complex* consists of a ridge or series of swellings running from the eye tubercle towards the anterior margin.

(4) An *antero-ventral complex* consists of a swelling below the antero-dorsal complex. It may run into the ventral ridge, and is sometimes connected to the sub-central tubercle.

(5) The anterior margin is raised to give the *anterior marginal rim*, and may be ornamented with a number of low tubercles. The margin itself frequently bears a row of small spines.

(6) A depressed region between the anterior marginal rim and the antero-dorsal and ventral complexes may be termed the *anterior plain.*

(7) A *dorsal ridge* connects the eye tubercle to the postero-dorsal complex.

(8) A *dorsal groove* lies immediately below the dorsal ridge and is often very deep. It sweeps round behind the antero-dorsal complex and joins the anterior plain between the antero-dorsal and ventral complexes.

(9) The *sub-central tubercle* (or *muscle scar node* of some authors) occupies a position slightly anterior to the centre.

(10) A *ventral ridge* connects antero-ventral and postero-ventral complexes.

(11) A *posterior hinge tubercle* corresponds to the posterior socket of the hinge ; it is therefore found on the left valve only (see Pl. XIII, fig. 3).

(12) The *postero-dorsal complex* is usually a high, angular ridge projecting over the dorsal margin and running transversally across the shell to the median line.

(13) The *postero-ventral complex* consists of a series of swellings running into each other and into the ventral ridge.

(14) The *posterior marginal rim* corresponds in position and ornamentation to the anterior marginal rim.

(15) There is a *posterior plain* between the posterior complexes and marginal rim.

The total number of specimens of *Cythereis* examined from the Boueti Bed numbers only ten. This assemblage shows considerable variation in ornament. It includes specimens which are close to the lectotype of *C. fullonica* (Pl. XII, fig. 8). I do not consider it advisable at this stage to name these variations. The number of specimens available has not been sufficient to determine whether or no they are of systematic or stratigraphic significance. Three varieties are figured on Pl. XII, in addition to the lectotype.

	Dimensions.	*Proportions.*
Lectotype (carapace, I. 1871) :	0·54, 0·32, 0·28 ;	1·69 : 1 : 0·87

The hinge structure of the right valve (Pl. XIII, fig. 9) shows anterior and posterior teeth divided into about four toothlets each, and set at an angle to the dorsal margin. Behind the anterior element is a triangular socket. A shallow groove originates above this socket and extends along the dorsal border to the posterior element.

Genus MONOCERATINA Roth, 1928

Genoholotype *M. ventrale* Roth

This genus can only with doubt be assigned to the Cytheracea.

MONOCERATINA HERBURYENSIS sp. nov.

Pl. XV, figs. 3–6

Description.—Anterior border evenly rounded, dorsal and ventral borders straight, parallel. Posterior gradually tapering to a blunt termination about one-third the height of the shell below the dorsal border.

	Dimensions.	*Proportions.*
Right valve (holotype) :	0·45, 0·20 ;	2·25 : 1

Ornament.—Four swellings surround the dorsal sulcus ; the two ventral swellings tend to coalesce into one (as in Pl. XV, fig. 4). The surface is covered by large irregular shallow punctae.

The hinge structure of the two valves is rather similar (Pl. XV, figs. 5 and 6). In the left valve a long straight bar with a very narrow groove above runs the length of the dorsal margin. There is a slight posterior terminal swelling and the suggestion of an anterior swelling. In the right valve there is a long straight groove with a posterior terminal swelling.

Occurrence.—About twenty examples from the Boueti Bed.

Remarks.—*M. herburyensis* is evidently closely allied to the larger species *M. vulsa* (Jones and Sherborn), from which it may be distinguished by the fact that in *M. vulsa* instead of four swellings ornamenting the valve there is one, crescentic in shape, surrounding the dorsal sulcus.

MONOCERATINA ACCENTUATA sp. nov.

Pl. XV, fig. 7

Description.—The four swellings of *M. herburyensis* are in this species accentuated as long blunt spines. The holotype is considerably larger than any specimen of *M. herburyensis* ; otherwise the two species resemble each other.

	Dimensions.	*Proportions.*
Left valve (holotype) :	0·64, 0·29 ;	2·21 : 1

Occurrence.—One specimen only from the Boueti Bed.

Genus CYTHERE Müller, sensu lato

" CYTHERE " sp. nov.

A species resembling *Cytheropteron* is represented by a few (10) specimens. The hinge differs from *Cytheropteron* and is like that of

Clithrocytheridea. The specimens available from the Boueti Bed are not well preserved and are unsuitable for founding a new genus. "*Cythere*" *subconcentrica* Jones, 1884, would seem to be of the same genus.

Sub-family PROGONOCYTHERINAE nov.

Diagnosis.—Inequivalve Cytheracea with straight hinge composed of three elements—anterior, posterior, and median—in which the median element is further subdivided into anterior and posterior portions. In the larger (left) valve the anterior and posterior elements are short, socketed grooves. The median element is a bar, the anterior portion of which is always denticulate, the posterior portion being distinguished by smaller toothlets or by mere crenulations. In the smaller (right) valve the anterior and posterior elements are short bars, the anterior always, the posterior usually, denticulate. The median element is clearly divided into an anterior groove with four or five distinct sockets, and a posterior groove, narrower than the anterior, with more numerous but less clearly defined sockets.

Description.—Shape and ornamentation variable, embracing two genera described below. Muscle scars characteristic of most members of the super-family, consisting of four vertical scars, closely approximated, with two other scars to the anterior, also vertically disposed but separated from each other. Normal pore canals large, few, scattered. Selvage of left valve projecting in centre of ventral margin, fitting into a groove similarly placed on the right valve, formed by selvage and inner list (see Text-fig. 2). Sexual dimorphy often apparent.

Remarks.—The hinge structure of this sub-family resembles closely that found in the ostracods *Cythere* and *Clithrocytheridea*. From these it can be distinguished by the subdivision of the median element, particularly noticeable in the right valve.

Genus PROGONOCYTHERE nov.

Genoholotype *Progonocythere stilla* sp. nov.

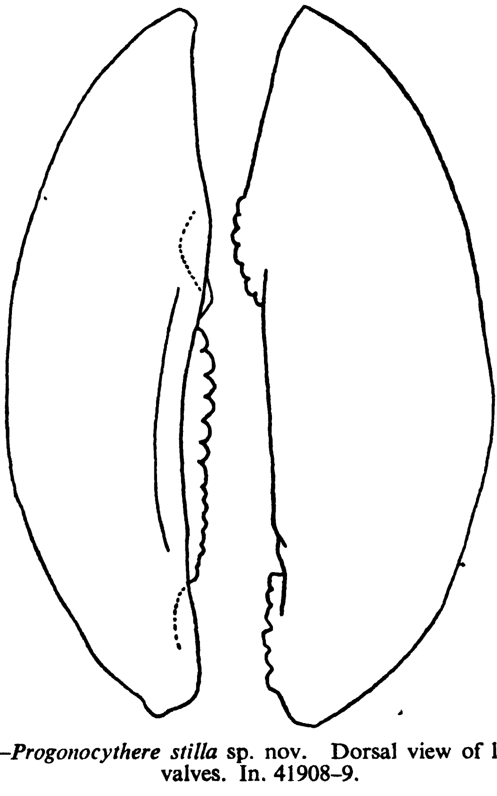
Diagnosis.—Progonocytherinae with hinge characteristic of the sub-family, smooth, or ornamented with transverse, longitudinal, or both transverse and longitudinal wrinkles or ridges, giving an irregular reticulate pattern.

Remarks.—This genus includes oval, oblong, and sub-rectangular species. The posterior may or may not be pointed. The anterior is evenly rounded. When Jurassic ostracods are better known it may be necessary to subdivide the genus.

PROGONOCYTHERE STILLA sp. nov.

Plate XII, figs. 1 and 2; Pl. XIII, figs. 1 and 2 ; Text-figs. 1 and 2

Description.—Carapace smooth, inflated, left valve the larger ; highest point in anterior third, tapering at about 40° to posterior. Anterior and posterior ends evenly rounded. Ventral margin obscured



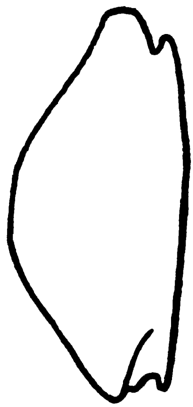
TEXT-FIG. 1.—*Progonocythere stilla* sp. nov. Dorsal view of left and right valves. In. 41908–9.

in lateral view by gibbosity. Dorsal margin of right valve irregular owing to slight projection of hinge angles. Dorsal margin of left valve evenly curved.

		Dimensions.	*Proportions.*
In. 41909.	Left valve :	0·65, 0·42, 0·20 ;	1·55 : 1
In. 41908.	Right valve (holotype) :	0·70, 0·40, 0·18 ;	1·75 : 1
	Carapace (width estimated) :		1·55 : 1 : 0·9

The shell is smooth and often translucent, when the muscle scars are visible from the outside. Normal pore canals few, scattered, large. Radial pore canals not discerned.

Hinge well developed (Text-fig. 1, and pl. XIII, figs. 1 and 2), the sub-division of the median element being particularly noticeable in the right valve. The anterior part of the median element of the left valve consists of four or five large teeth ; the posterior part consists of a row of smaller teeth. There is a slight " accommodation groove " (the " ausweichsfurche " of Triebel) above the median element of the left valve. It forms a shelf rather than a groove. The sockets of the



TEXT-FIG. 2.—*Progonocythere stilla* sp. nov. End view of left valve. In. 41909.

terminal elements of the left valve are in deep recesses, overhung by the dorsal margin.

Occurrence.—Fourteen single valves from the Boueti Bed.

PROGONOCYTHERE BLAKEANA (Jones)

Pl. XII, figs. 3 and 4 ; Pl. XIII, figs. 4 and 5 ; Text-figs. 3 and 4

Cythere blakeana, Jones, 1884, p. 772, pl. 34, figs. 34, 35.
Cytheridea transversiplicata, Jones and Sherborn, 1888, p. 267, pl. 3, fig. 4.
Cytheridea egregia, Jones and Sherborn, 1888, p. 267, pl. 3, fig. 5.
? *Cytheridea blakeana*, Jones and Sherborn, 1888, p. 265, pl. 2, fig. 11.

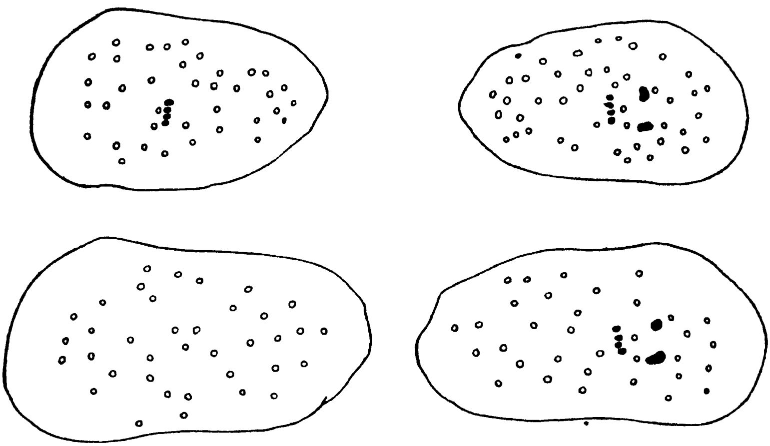
Description.—Dimorphic, the presumed males longer in proportion than the females, which are the more abundant (see Text-fig. 3). Left valve larger than the right, overlapping it on all margins (see Text-fig. 4). Carapace highest in anterior third. Dorsal margin of left valve slightly concave, of right valve slightly convex. Posterior margin triangular, especially in right valve.

Dimensions.

In. 41912.	Left valve female . .	0·60, 0·33
In. 41913.	Right valve female . .	0·57, 0·32
In. 41915.	Left valve male . .	0·73, 0·38
In. 41916.	Right valve male . .	0·69, 0·36
In. 41914.	Carapace female . .	0·57, 0·33, 0·31
In. 41950.	Left valve female (lectotype)	0·68, 0·38
In. 41947.	Carapace male. . .	0·67, 0·36, 0·32

Proportions.

In. 41914.	Carapace female . .	1·73 : 1 : 0·94
In. 41917.	Carapace male. . .	1·86 : 1 : 0·89



TEXT-FIG. 3.—*Progonocythere blakeana* (Jones). External lateral views of left and right valves of male (below) and female (above); showing muscle scars and normal pore canals. In. 41913, 41915, 41916.

Ornament consisting of low wrinkles which form a reticulate pattern, the transverse plications appearing more obvious in the dorsal part of the shell, the longitudinal in the ventral part. Normal pore canals large, tending to give rise to shallow pits at the surface. In some specimens it is the wrinkles that form the most obvious ornament, in others the pits. The difference is possibly one of preservation.

Normal pore canals large, few, scattered. Radial pore canals not observed. Muscle scar of usual *Cythere* pattern (Text-fig. 3).

Occurrence.—The lectotype is from the Richmond boring. The species is the most common ostracod of the Boueti Bed. A pound sample produces some hundreds of specimens after washing.

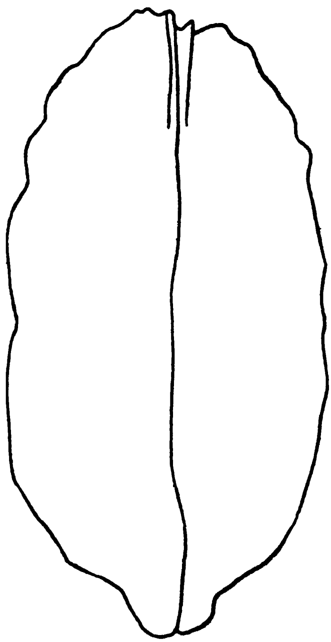
Remarks.—The distinction between *C. egregia* and *C. transversiplicata* (from the Fuller's Earth of Bath) made by Jones and Sherborn was on slight differences of shape. Each species was founded

on a single specimen. The two specimens fit into the variation exhibited by *P. blakeana* in the Boueti Bed. The specimen figured as *C. blakeana* by Jones and Sherborn is perhaps the young of another species.

PROGONOCYTHERE JUGLANDICA (Jones)

Pl. XII, figs. 5 and 6 ; Pl. XIII, fig. 8

Cythere juglandica Jones, 1884, pp. 766, 768, and pl. 34, figs. 36, 37.
Cythere juglandica var. *major*, Jones and Sherborn, 1888, p. 255, and pl. 4, fig. 2.
(not *Cythere juglandica* var. *minor* Jones and Sherborn, 1888.)



TEXT-FIG. 4.—*Progonocythere blakeana* (Jones). Dorsal view of carapace. In. 41914.

Description.—Left valve considerably larger than the right, and of different outline. Left valve rounded in front ; dorsal and ventral margins sub-parallel, the dorsal concave, the ventral convex ; ventral margin tapering evenly to a projection directed upwards. Right valve rounded in front, dorsal margin straight, the ornamentation of the carapace projecting upwards above it in the centre, giving something of the appearance of an umbo. Ventral margin convex ; valve tapering to the posterior, which is triangular with a marked postero-cardinal angle.

		Dimensions.	Proportions.
In. 41949.	Carapace (metatype) .	0·75, 0·48, 0·50	1·56 : 1 : 1·04
In. 41910.	Left valve . .	0·72, 0·43	1·67 : 1
In. 41911.	Right valve . .	0·72, 0·39	1·85 : 1

Ornament consisting of irregular coarse ridges which are parallel to the ventral margin in the ventral area, and radiate outwards from the centre of the dorsal margin in the rest of the carapace (the point of origin projecting above the dorsal margin in the right valve, as mentioned above); connecting ridges give an irregular reticulate pattern.

Pore canals not discerned. Hinge details as for genus.

Occurrence.—(*a*) Five specimens from the Boueti Bed; (*b*) Jones (1884), five or more specimens from the Richmond boring, in strata presumed to be Lower Cretaceous, but probably derived from the Bathonian below; (*c*) Jones and Sherborn (1888), one specimen from the Bradford Clay.

Remarks.—Right and left valves are dissimilar in proportions and shape; examination of metatypes of the complete carapace from the Richmond boring shows that the type and the var. *major* of Jones and Sherborn are right and left valves of the same species. The strong ornament is distinctive, and the " false umbo " of the right valve is suggestive of the feature claimed as diagnostic of the genus *Isocythere* by Terquem (1885). A recent examination of Terquem's genotype (*Isocythere nova*) has shown, however, a different hinge structure. Moreover, the ornament figured and described by Terquem appears to be largely imaginary.

Genus Lophocythere nov.

Genoholotype *Cytheridea ostreata* Jones and Sherborn, 1888

Diagnosis.—Progonocytherinae bearing one or more sharp keels (carinae) along the flanks, approximately parallel to the ventral and dorsal borders.

Description.—Usually reticulate, the reticulae extending on to the keels. The walls of this meshwork are sometimes produced as spinous processes or thin lamellae. Eye tubercle usually strongly developed. The shape of the adult is often somewhat rectangular, dorsal and ventral margins being approximately parallel, anterior end broadly rounded, posterior end produced to a point. Sexual dimorphy apparent, one sex (presumed to be the male) being considerably more elongate than the other. The females are more common than the males. The young moults commonly taper to the posterior, in contrast to the adults.

Remarks.—The characteristic ornament of this genus recalls a trend apparent in certain Miocene ostracods described by Coryell and Fields (1937), in which, however, the carinae are not only reticulate, but actually perforate.

The shape and ornament recall certain species of *Cythereis* (from which genus *Lophocythere* can at once be distinguished by its hinge structure).

LOPHOCYTHERE OSTREATA (Jones and Sherborn)

Pl. XIV, figs. 1–4 ; Pl. XV, figs. 1 and 2.

Cytheridea ostreata, Jones and Sherborn, 1888, p. 271, pl. 4, fig. 6.
Cytheridea bicarinata, Jones and Sherborn, 1888, pp. 270, 271 ; pl. 4, fig. 5.

Description.—Left valve considerably the larger, overlapping the right particularly along the dorsal margin. Both valves of the adult with rounded anterior border ; straight, parallel dorsal and ventral borders, and posterior produced to a point at about the centre line. Juvenile moults resemble the adults except that they taper towards the posterior, the prolongation of which is directed upwards.

		Dimensions.	*Proportions.*
In. 41922.	Carapace .	. 0·70, 0·39, 0·38	1·89 : 1 : 0·98
In. 41918.	Left valve .	. 0·76, 0·41	1·85 : 1
In. 41919.	Right valve .	. 0·73, 0·36	2·00 : 1
In. 41920.	Left valve (juv.).	. 0·58, 0·33	1·76 : 1
In. 41921.	Right valve (juv.)	. 0·54, 0·32	1·68 : 1

There are two strong carinae. The ventral one forms the ventral margin. Closely parallel to it, the second runs the length of the shell and curves round at the anterior end parallel to the anterior margin, and runs into the eye tubercle. The valves are covered by high-walled reticulae which run up the carinae. In places the walls of the reticulae are produced into short ridges or small spinous tubercles. Of these ridges three are conspicuous, one in the antero-central region, the other two near the postero-dorsal margin. These two posterior ridges are not separated in the juvenile moults. In the adult the posterior one projects above the dorsal margin in the right valve.

The hinge structure is characteristic of the sub-family. Pore canals not discerned.

Occurrence.—About eighty specimens from the Boueti Bed. The species is common in the Fuller's Earth, and seems to be the most abundant member of the genus in the Bathonian.

Remarks.—The holotype of Jones and Sherborn (from the Fuller's

Earth of Midford) is a broken right valve. Their "*Cytheridea bicarinata*" is a juvenile moult of the same species.

LOPHOCYTHERE BRADIANA (Jones)

Pl. XIV, figs. 7–10; Pl. XV, figs. 8–11.

Cythere bradiana, Jones, 1884, p. 772 and pl. 34, fig. 38, not *Cytheridea bradiana*, Jones and Sherborn, 1888.

Description.—Dimorphic, the presumed males longer in proportion than the females. Carapace sub-rectangular; left valve larger than the right. Dorsal margin of left valve concave, projecting noticeably at the antero-cardinal angle in the region of the eye tubercle. Dorsal margin of right valve rendered convex by the projection above it of the dorsal carina. Anterior margin of both valves unevenly rounded, deflected towards venter. Posterior margin of both valves triangular, pointed. Dorsal and ventral margins of both valves sub-parallel. Ventral carina projecting below ventral margin in posterior half of both valves.

		Dimensions.	*Proportions.*
In. 41923.	Left valve male . .	0·76, 0·39	1·95 : 1
In. 41925.	Left valve, female . .	0·67, 0·39	1·72 : 1
In. 41924.	Right valve, male . .	0·74, 0·33	2·24 : 1
In. 41926.	Right valve, female juv. .	0·56, 0·31	1·81 : 1

There are four main carinae, and two minor. The dorsal carina slopes diagonally from the central point of the anterior margin below the eye tubercle to the anterior third of the dorsal margin. From here it sweeps in a gentle curve to the middle point of the posterior border. In the right valve it projects over the dorsal margin. The two median carinae are united at the anterior end, where the combined stem originates just below the dorsal carina, and runs parallel to it for about one-quarter the length of the shell. The dorsal branch of the median carina is then deflected as a median longitudinal keel. The ventral branch is given off about an eighth of the shell's length from the anterior end, runs parallel to the ventral margin, and curves round at the posterior end almost to meet the dorsal carina. The ventral carina originates below the median and runs to the posterior margin, projecting below the ventral border in the posterior half. One minor carina is developed in the postero-dorsal region between the dorsal and the dorso-median carinae; the other minor carina runs along the antero-ventral half of the shell between the ventral and the ventro-median carinae. A third faint minor ridge is sometimes developed between the two median carinae.

High-walled reticulae cover the interspaces between the carinae.

The hinge is characteristic of the sub-family, the subdivision of the median element being particularly obvious. A shallow accommodation groove is developed in the left valve.

Occurrence.—About thirty specimens from the Boueti Bed.

Remarks.—This species closely resembles *L. craticula* (Jones and Sherborn). The details of the carina patterns serve to distinguish the two sub-species. In particular, in *L. bradiana* the dorsal carina makes an angular bend behind the eye tubercle, and from there cuts diagonally across to the anterior margin, but does not join the same stem as that of the two median carinae. In *L. craticula* on the other hand, there is a short anterior stem from which spring the dorsal, the two median, and the ventral carinae.

LOPHOCYTHERE CARINILIA sp. nov.

Pl. XIII, figs. 6, 7 ; Pl. XIV, figs. 5, 6.

Description.—Small *Lophocythere*, sub-rectangular in shape, with posterior directed clearly upwards.

		Dimensions.	*Proportions.*
In. 41929.	Left valve . . .	0·60, 0·32	1·87 : 1
In. 41927.	Right valve (holotype) .	0·58, 0·28	2·07 : 1
In. 41930	Carapace . . .	0·60, 0·31, 0·31	1·93 : 1 : 1·00

Only two main carinae are developed, the median and ventral, which are both longitudinal and approximately parallel. Three minor carinae are developed : (i) the antero-dorsal, running from near the mid-point of the anterior margin into the eye tubercle, and sometimes a short distance backwards from the eye tubercle along the dorsal margin ; (ii) the postero-dorsal, running upwards as a branch from the posterior end of the median carina ; often obsolescent ; (iii) the sub-ventral, running the length of the carapace below the ventral, and forming the ventral border. High-walled reticulae decorate the interspaces between the carinae.

The subdivision of the median element of the hinge, the diagnostic feature of the sub-family, is difficult to discern in this species. The anterior portion of the median groove of the right valve is very slightly wider than the posterior portion.

Occurrence.—About forty specimens from the Boueti Bed.

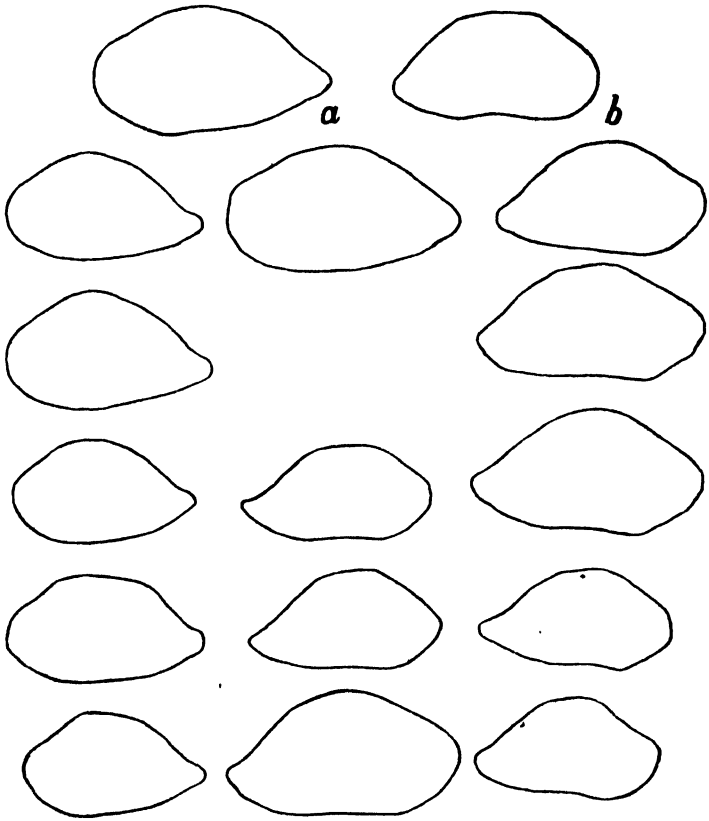
Superfamily BAIRDIACEA nov.

Genus BAIRDIA McCoy, 1846

Genotype, *Bairdia curta* McCoy.

The following nine specific names, assigned to the genus *Bairdia* by

their authors, have been introduced for Middle Jurassic specimens: *B. gingensis* by Waagen (1867); *B. hilda, B. jurassica* and var. *tenuis, B. juddiana, B. trigonalis* by Jones (1884); *B. affinis* by Terquem (1885); *B. ovula, B. suborbicularis* by Terquem (1886); *B. fullonica*



TEXT-FIG. 5.—*Bairdia cf. hilda* Jones. Lectotypes of *B. hilda* (*a*) and "*B. fullonica*" (*b*), and examples from the Boueti Bed. In. 41951, I. 1873, In. 41931–44.

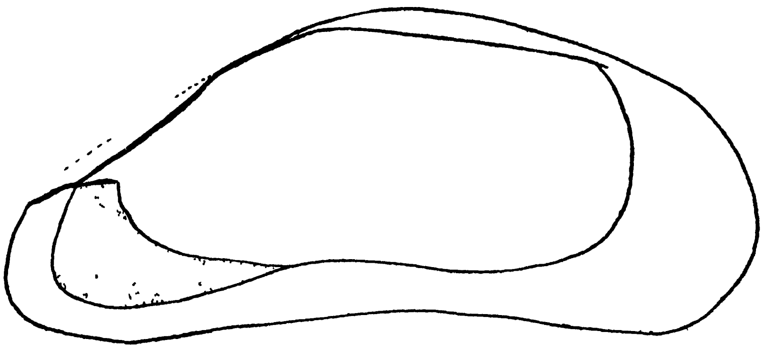
by Jones and Sherborn (1888). Their distinction has been entirely by differences of outline. There is considerable variation in an assemblage of specimens from one horizon. Probably some of the species are synonyms. Others have been incorrectly assigned to the genus. Terquem's species seem badly drawn, and require refiguring.

BAIRDIA cf. HILDA Jones, 1884

Text-fig. 5

Bairdia hilda, Jones, 1884
Bairdia fullonica, Jones and Sherborn, 1888

I have ascribed all the specimens found in the Boueti Bed to this one species. The extent of variation is indicated by the outline drawings of Text-fig. 5. The lectotypes of *B. hilda* and *B. fullonica* are figured on the same scale for comparison. Statistical comparisons of the range



TEXT-FIG. 6.—? *Bythocypris* sp. Broken left valve. Stippled area marks vestibule In. 41945.

of variation form the only satisfactory method of differentiating species in which the diagnostic character is shape alone. There is as yet no evidence for regarding the species *hilda* and *fullonica* as distinct, and they are here quoted as synonyms.

The fine punctation observed and figured by Jones and Sherborn in their description of *B. fullonica* can be made out on most but not all of the specimens here figured.

Occurrence.—Over one hundred specimens from the Boueti Bed.

Genus BYTHOCYPRIS Brady, 1880

Genolectotype *Bythocypris reniformis* Brady

? BYTHOCYPRIS sp.

Five broken valves of a very thin shelled species, much produced towards the postero-ventral corner (Text-fig. 6), may doubtfully be assigned to *Bythocypris*.

Sub-Order **Platycopa** Sars

Family CYTHERELLIDAE Sars

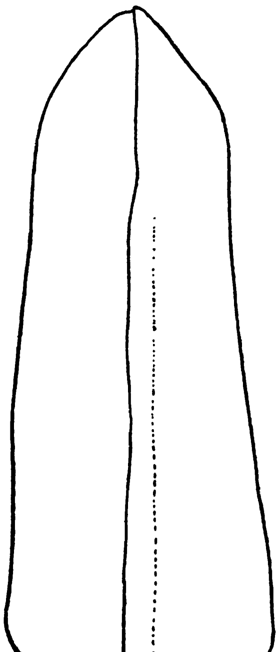
Genus CYTHERELLOIDEA Alexander, 1929

Genoholotype *Cytherella williamsoniana* Jones, 1850

? CYTHERELLOIDEA CATENULATA (Jones and Sherborn)

Text-fig. 7 and Pl. XIV, fig. 11

Cytherella catenulata, Jones and Sherborn, 1888, p. 274, pl. 5, fig. 6.



TEXT-FIG. 7.— ? *Cytherelloidea catenulata* (Jones and Sherborn). Dorsal view of carapace. In. 41946.

Description.—Usual compressed shape (see Text-fig. 7), characteristic of the genus. Surface covered by regular lines of punctae. Posterior crescentic swelling, with a small depression in front of its ventral arm. An irregular group of depressions below the centre of the dorsal margin.

	Dimensions.	*Proportions.*
Carapace . . .	0·67, 0·36, 0·23	1·86 : 1 : 0·64

Occurrence.—About twenty-five specimens from the Boueti Bed. This species is abundant in the Fuller's Earth.

Catalogue of Specimens Lodged in the British Museum

Locality and horizon of all specimens Boueti Bed, Herbury, unless otherwise stated.

Cythereis fullonica Jones and Sherborn.

Lectotype. Carapace. (Fuller's Earth, Midford.) (Figured Jones and Sherborn, 1888, and this paper, Pl. XII, fig. 8.) I. 1871.

Cythereis cf. fullonica.

Plesiotypes :—

Carapace (Pl. XII, fig. 7). In. 41901.
Carapace (Pl. XII, fig. 9 ; Pl. XIII, fig. 3). In. 41902.
Right valve (Pl. XII, fig. 10 ; Pl. XIII, fig. 9). In. 41903.

Monoceratina herburyensis sp. nov.

Holotype. Right valve (Pl. XV, fig. 3). In. 41904.

Paratypes :—

Right valve (Pl. XV, figs. 4 and 5). In. 41905.
Left valve (Pl. XV, fig. 6). In. 41906.

Monoceratina accentuata sp. nov.

Holotype. Left valve. In. 41907

Progonocythere stilla sp. nov.

Holotype. Right valve (Pl. XII, fig. 2 ; Pl. XIII, fig. 1 ; Text-fig. In. 41908.

Paratype. Left valve (Pl. XII, fig. 1 ; Pl. XIII, fig. 2 ; Text-figs. 1 and 2). In. 41909.

Progonocythere juglandica (Jones).

Lectotype. Right valve (Richmond boring, 1,146 ft. 6 in.). In. 41947.

Metatypes. Carapaces (Richmond boring, 1,151 ft. 6 in.). In. 41948–41949.

Plesiotypes :—

Left valve (Bradford Clay. The holotype of " *Cythere juglandica* var. *major* " Jones and Sherborn, 1888, Pl. 4, fig. 2). I. 1872.
Left valve (Pl. XII, fig. 5). In. 41910.
Right valve (Pl. XII, fig. 6 ; Pl. XIII, fig. 8). In. 41911.

Progonocythere blakeana (Jones).

Lectotype. Left valve (Richmond boring, 1,205 feet). (Figured Jones, 1884, pl. 34, figs. 34, 35.) In. 41950.

Plesiotypes :—

Left valve, female (Pl. XII, fig. 3). In. 41912.
Left valve, female (Pl. XIII, fig. 4 ; Text-fig. 3). *Specimen lost.*
Right valve female (Pl. XII, fig. 4 ; Pl. XIII, fig. 5 ; Text-fig. 3). In. 41913.
Carapace female (Text-fig. 4). In. 41914.
Left valve male (Text-fig. 3). In. 41915.
Right valve male (Text-fig. 3). In. 41916.

Specimen referred to in text, but not figured : carapace, male. In. 41917.

Lophocythere ostreata (Jones and Sherborn).

Plesiotypes :—

Left valve (Pl. XIV, fig. 1 ; Pl. XV, fig. 1). In. 41918.
Right valve (Pl. XV, fig. 2 ; Pl. XV, fig. 2). In. 41919.
Left valve juv. (Pl. XIV, fig. 3). In. 41920.
Right valve juv. (Pl. XIV, fig. 4). In. 41921.

Specimen referred to in text, but not figured : carapace. In. 41922.

Lophocythere bradiana (Jones).

Plesiotypes :—

Left valve male (Pl. XIV, fig. 8 ; Pl. XV, fig. 8). In. 41923.
Right valve male (Pl. XIV, fig. 7 ; Pl. XV, fig. 10). In. 41924.
Left valve female (Pl. XIV, fig. 9 ; Pl. XV, fig. 9). In. 41925.
Right valve female juv. (Pl. XIV, fig. 10 ; Pl. XV, fig. 11). In. 41926.

Lophocythere carinilia sp. nov.

Holotype. Right valve (Pl. XIII, fig. 7 ; Pl. XIV, fig. 6). In. 41927.

Paratypes :—

Left valve (Pl. XIII, fig. 6). In. 41928.
Left valve (Pl. XIV, fig. 5). In. 41929.

Specimen referred to but not figured : carapace. In. 41930.

Bairdia hilda Jones.

Lectotype. Left valve (Text-fig. 5*a*, and Jones, 1884, pl. 34, fig. 20). (Richmond boring, 1,205 feet.) In. 41951.

Plesiotypes (Text-fig. 5). In. 41931–41944.

? *Bythocypris* sp.

Left valve (Text-fig. 6). In. 41945.

? *Cytherelloidea catenulata* (Jones and Sherborn).

Plesiotype. Carapace. (Pl. XIV, fig. 11 ; Text-fig. 7.) In. 41946.

ACKNOWLEDGMENTS

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The author would like to express his gratitude to Dr. Helen M. Muir-Wood and the authorities of the British Museum for their courtesy in making available museum specimens.

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EXPLANATION OF PLATES

PLATE XII

FIGS. 1 and 2.—*Progonocythere stilla* sp. nov. ; 1, left valve ; 2, right valve ; external lateral views.

FIGS. 3 and 4.—*P. blakeana* (Jones), female ; 3, left valve ; 4, right valve ; external lateral views.

FIGS. 5 and 6.—*P. juglandica* (Jones) ; 5, left valve ; 6, right valve ; external lateral views.

FIGS. 7–10.—*Cythereis cf. fullonica* Jones and Sherborn ; 7, 8, and 9, carapaces ; 10, right valve ; 8 is the lectotype ; external lateral views of right valve.

PLATE XIII

FIGS. 1 and 2.—*Progonocythere stilla* sp. nov. ; 1, right valve ; 2, left valve ; internal lateral views.

FIG. 3.—*Cythereis cf. fullonica* Jones and Sherborn ; carapace, dorsal view.

FIGS. 4 and 5.—*Progonocythere blakeana* (Jones), female ; 4, left valve ; 5, right valve ; internal lateral views.
FIGS. 6 and 7.—*Lophocythere carinilia* sp. nov. ; 6, left valve ; 7, right valve ; internal lateral views.
FIG. 8.—*Progonocythere juglandica* (Jones) ; right valve, internal lateral view.
FIG. 9.—*Cythereis cf. fullonica* (Jones and Sherborn) ; right valve, internal lateral view.

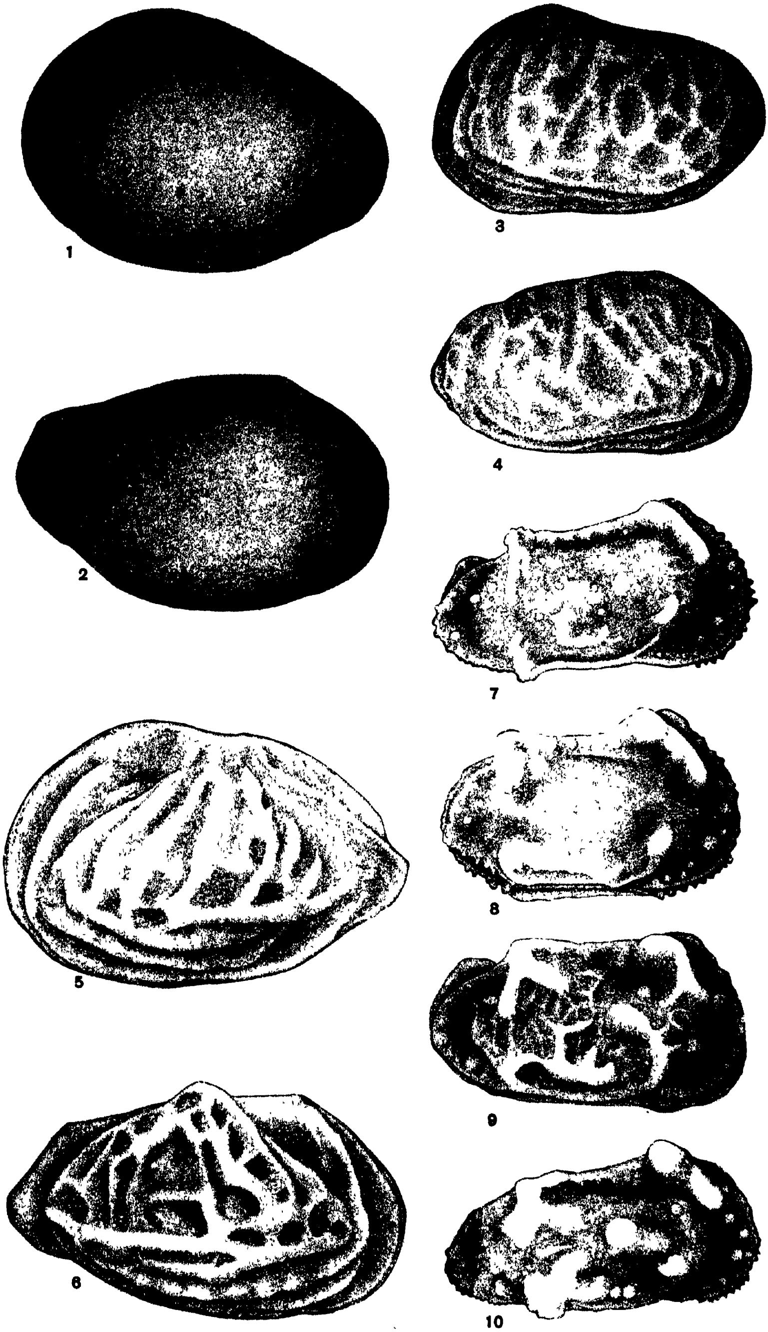
PLATE XIV

FIGS. 1–4.—*Lophocythere ostreata* (Jones and Sherborn) ; 1, left valve ; 2, right valve ; 3, left valve juv. ; 4, right valve juv. ; external lateral views.
FIGS. 5 and 6.—*L. carinilia* sp. nov. ; 5, left valve ; 6, right valve ; external lateral views.
FIGS. 7–10.—*L. bradiana* (Jones) ; 7, right valve male ; 8, left valve male ; 9, left valve female ; 10, right valve female juv. ; external lateral views.
FIG. 11.—*? Cytherelloidea catenulata* (Jones and Sherborn) ; carapace, external lateral view of left valve.

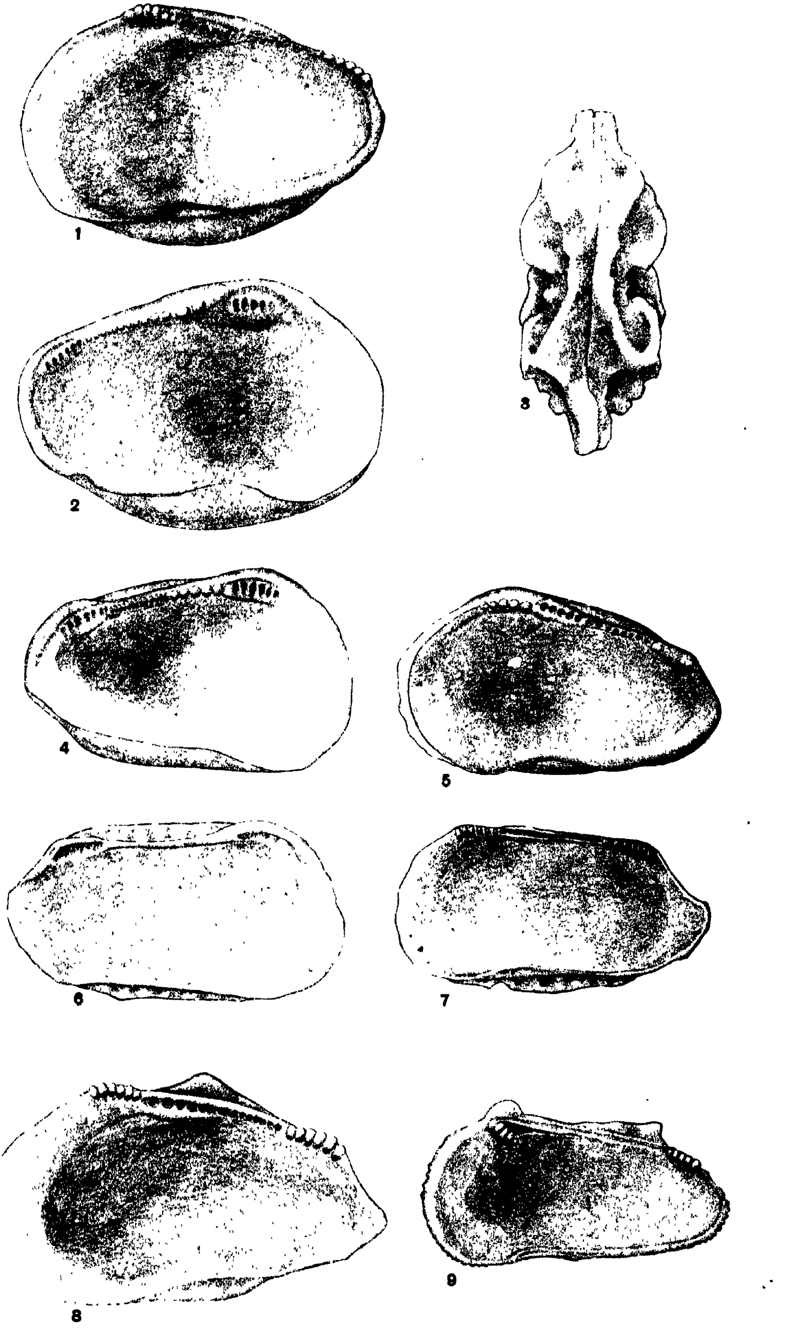
PLATE XV

FIGS. 1 and 2.—*Lophocythere ostreata* (Jones and Sherborn) ; 1, left valve ; 2, right valve ; internal lateral views.
FIGS. 3–6.—*Monoceratina herburyensis* sp. nov. ; 3, 4, right valves, external lateral views ; 5, right valve, internal lateral view ; 6, left valve, internal lateral view.
FIG. 7.—*Monoceratina accentuata* sp. nov. Left valve, external lateral view.
FIGS. 8–11.—*Lophocythere bradiana* (Jones) ; 8, left valve male ; 9, left valve female ; 10, right valve male ; 11, right valve female juv. ; internal lateral views.

Note.—The scale of all figures is approximately × 80. Exact dimensions are quoted in the text.



BATHONIAN OSTRACODS.



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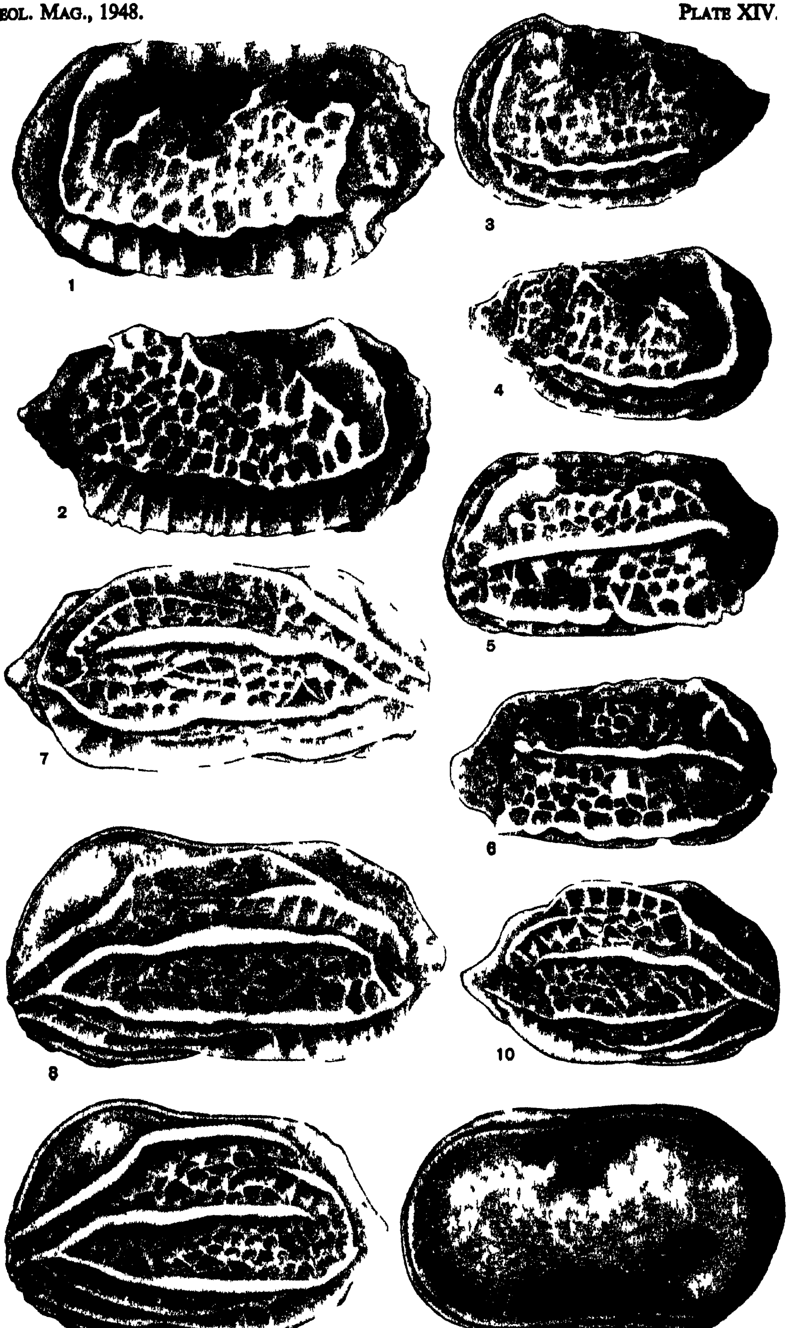

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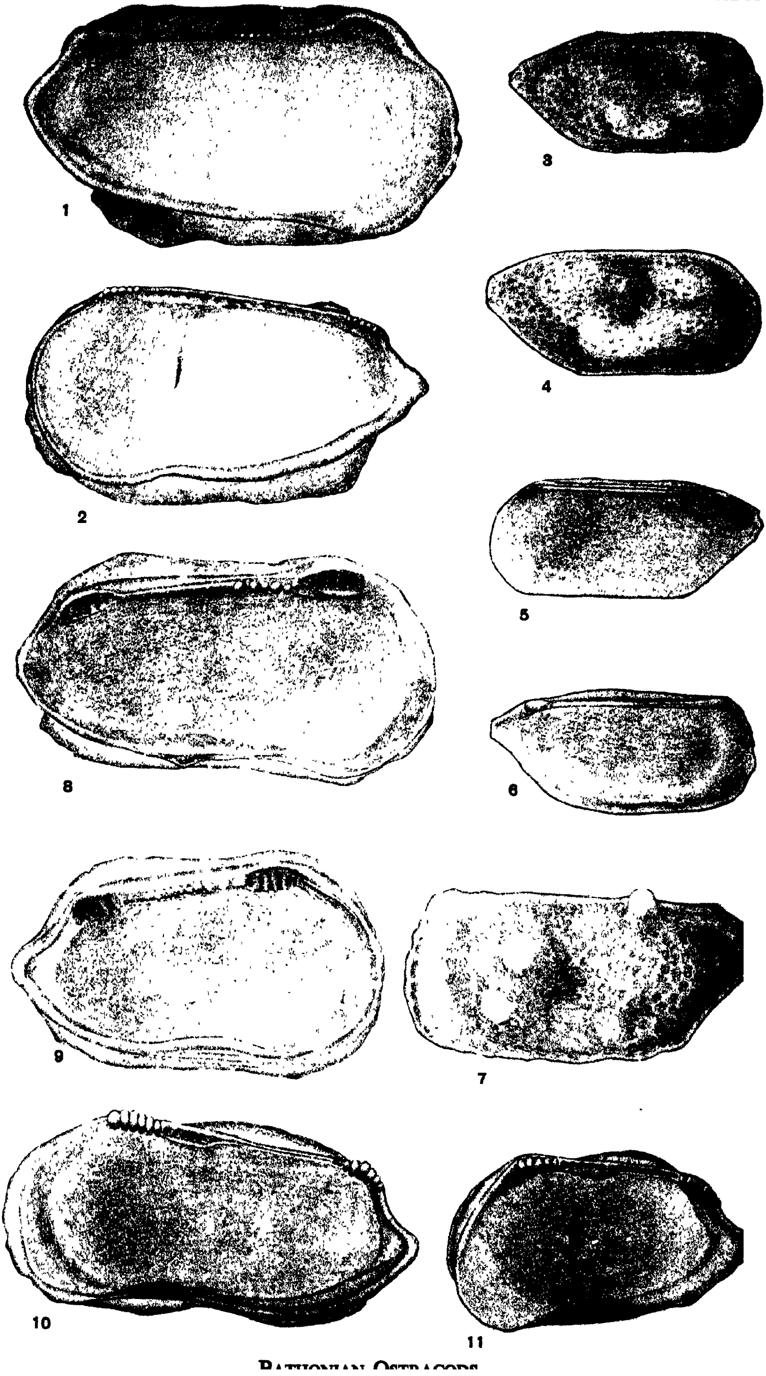


BATHONIAN OSTRACODS

On the Lower Part of the Ashgillian Series in the North of England

By W. B. R. KING and ALWYN WILLIAMS (Sedgwick Museum, Cambridge)

(PLATE XVI)

THE Ashgillian as the name for the uppermost series of the Ordovician system was proposed by Marr in his address to the Geological Society in 1905, and subsequently further justified by him in a paper in the *Geological Magazine* in 1907.

In 1913 he described the rocks of this age in the Cautley district of Westmorland and N.W. Yorkshire, and stated that this succession " should be taken as the type for the Ashgillian Series of Northern England ". In 1916 he redescribed the original Ashgill sections of the Coniston area (Lake District).

In the Cautley area Marr summarizes the succession as follows :—

Ashgillian	Upper	Ashgill Shales
	Middle	*Staurocephalus* beds
	Lower	*Phacops robertsi* beds
Caradocian	*Calymene* beds	

In this area the base of the *Calymene* beds is not seen, but it has always been accepted that they form part of the " Coniston Limestone " of the Lake District which is seen to rest, in places with marked unconformity, upon the Borrowdale Volcanic series.

In all Marr's publications the base of the Ashgillian was taken at the base of the *Phacops robertsi* beds, which beds yield the *Phillipsinella parabola* fauna with occasional specimens of *Dicellograptus anceps*. The trilobite-brachiopod fauna of this horizon is well known from many British and European localities, and appears to lie within the zone of *Dicellograptus anceps* in the graptolite scale, but it is not clear whether the base of the *Ph. parabola* zone coincides with that of the *Dicellograptus anceps* zone or not.

In the Girvan area Lamont has recently described the fauna of the Lower Drummuck beds which come between the *Phillipsinella parabola* fauna (Upper Drummuck) and the Whitehouse beds with *Dicellograptus complanatus* and the *Cyclopyge* fauna. In the paper noted, Lamont (1935, p. 302) points out that his Lower Drummuck with their definitely Ashgillian type of fauna will probably be found to be equivalent to the *Calymene* beds of Cautley. In this he has been followed by Shirley (1936, p. 416) and Whittington (1938, p. 436).

It is necessary, then, to consider the reasons why Marr placed the *Calymene* beds in the Caradocian.

In many areas, particularly parts of Wales, the *Phillipsinella parabola*

beds rest upon strata which yield a typical Caradocian fauna. No angular unconformity can be seen in any single section, but Bancroft has claimed the presence of a strong non-sequence as a result of faunal studies of the Caradocian, and the evidence for this appears to be sound.

The details of the faunas of the Upper Caradocian beds are now known largely through the studies of Bancroft, Stubblefield, and Whittington. When Marr was studying the Cautley area, this detailed work was not available, and the allocation of the *Calymene* beds to the Caradocian was largely due to the abundance of what was identified as *Calymene planimarginata* Reed, which is a typical Caradocian trilobite. Together with this trilobite were a few other forms (trilobites and brachiopods) obviously distinct from the overlying *Phillipsinella parabola* fauna and having a superficial likeness to Caradocian forms.

Shirley (1936) has shown that the Cautley *Calymene* is not *planimarginata* Reed, but his new *Diacalymene marginata*, which comes from the Lower Drummuck of Girvan.

It was therefore clearly desirable to make fuller collections from the *Calymene* beds and study their fauna.

One of us (W. B. R. K.) has been collecting for a number of years, particularly in the Sally Brow area, and an extensive trilobite-brachiopod fauna has been obtained. This fully bears out Lamont's suggestion that the *Calymene* beds are equivalent to his Lower Drummuck beds (the Quarrel Hill mudstones).

A study of the fauna indicates clearly that it is not a Caradocian fauna at all, but that the fossils are either Ashgillian forms occurring also in the *Phillipsinella parabola* beds or are Lower Drummuck forms or new. There therefore seems good reason for accepting the *Calymene* beds as part of the Ashgillian Series. If this is done, then the Ashgillian Series of the North of England will contain three main faunas :—

Ashgillian	Upper	*Phacops mucronatus* fauna (including the Ashgill Shales)
	Middle	*Phillipsinella parabola* fauna (including the *Staurocephalus* beds and *Phacops robertsi* beds of Marr)
	Lower	*Diacalymene marginata* fauna = *Calymene* beds of Marr

At Girvan the Upper and Lower Drummuck group corresponds, in general, with the *Phillipsinella parabola* beds and the *Diacalymene* beds respectively, and the *Phacops mucronatus* beds appear to be cut out by the Valentian unconformity. Some of the brachiopods like *Orthis* (*Hirnantia*) *sagittifera*, which normally belong to the *Ph.*

mucronatus beds, are found at Girvan in the basal Valentian sandstones, but perhaps it is to be expected that some of these forms would continue to live for a short time into the Valentian, where the environment was propitious.

There is some evidence in the Austwick area (King and Wilcockson, 1934, p. 13) that *Phillipsinella parabola* occurs well up in the Middle Ashgillian in beds contemporaneous with the *Staurocephalus* beds of Cautley, for the zone fossil was obtained from strata immediately below the Wharfe Conglomerate and well above the Volcanic Ash horizon, while a little above the conglomerate were beds yielding a fauna which contained forms indicative of the *Ph. mucronatus* horizon but with certain other fossils. When this area was described in 1934 (pp. 10 and 11) some doubt was expressed regarding the age of the limestones of Crag Hill in Ribblesdale and although several forms normally found in the *Phillipsinella parabola* beds were noted, the conclusion was expressed that the beds were high Caradocian in age. This was when the *Calymene* beds were considered to be Caradocian. It is now felt that in all probability the Crag Hill beds, like the *Calymene* beds of Cautley, belong to the lowest member of the Ashgillian as here defined.

In North Wales, in those areas where the fauna is essentially a trilobite-brachiopod one, the correlation is fairly clear—for instance, at Bala the *Ph. mucronatus* beds and the "*Strophomena*" *hirnantensis*[1] beds are found in the well known Hirnant horizon and beds immediately beneath, while the *Ph. parabola* fauna is represented in the Rhiwlas Limestone and Mudstones. The beds below the Rhiwlas have been shown by Bancroft (1928, p. 484) to be well down in the Caradocian, and so the *Diacalymene* beds are missing.

In the Meifod area, to the east of Bala, King, 1928, showed that above the typical *Ph. parabola* beds is the *Calymene quadrata* zone. This is not represented as fossiliferous strata at Bala, and in the Cautley area this zone presumably occupies the place of part of Marr's *Staurocephalus* beds. This discrepancy may be due to the somewhat peculiar lithology of these beds in the North of England.

In places in Wales (Montgomeryshire) the *Ph. parabola* beds rest on black graptolitic shales variously known as the Pen-y-garnedd shales or the Gwern-y-brain shales, the exact age of which is not yet fully established, but everywhere the break between them and the *Ph. parabola* beds is sharp, probably a non-sequence, and it is more likely that the *Diacalymene marginata* beds are missing than that they are represented by the upper beds of these black shales.

In Central Wales the base of the Abercwmeiddaw group has been

[1] One of us (A.W.) has been studying this form and intends to publish a note shortly

shown by Pugh (1929, pp. 261, 263, and 303) to pass laterally into the Rhiwlas Limestone and Rhiwlas Mudstones with its *Ph. parabola* fauna. Normally in Central Wales the Abercwmeiddaw beds rest apparently with no break upon the black shales of the Nod Glas (Pugh, 1923, 1928). This group yields graptolites of the *Dicranograptus clingani* zone and probably the lower part of the *Pleurograptus linearis* zone.

Some 600 feet above the base of the Abercwmeiddaw beds Pugh has found a *Cyclopyge-Trinucleus albidus* fauna which he equates with the Whitehouse Group of Girvan and the *Dicellograptus complanatus* beds.

In the Girvan area we have seen that the Lower Drummuck beds come between the *Ph. parabola* or Upper Drummuck and the Whitehouse *Cyclopyge* beds, while in the Cautley area the *Ph. parabola* fauna is associated with *Dicellograptus anceps* and overlies beds which still have an Ashgillian and not a Caradocian fauna.

The question of correlation between the Cautley and Girvan rocks and their faunas with those of Central Wales must therefore be left for further investigation. (see Stubblefield, 1939, p. 61).

Bancroft has studied the Ordovician rocks of the Cross Fell area, and for our purposes the relevant part may be summarized as follows :

Ashgillian (in Bancroft's sense).	*Staurocephalus* Limestone with *Tretaspis seticornis.*
Pusgillian . . .	Upper *Tretaspis kjaeri* beds.
Onnian . . .	Beds with *Onnia.*
Actonian . . .	Lower *Tretaspis kjaeri* beds.

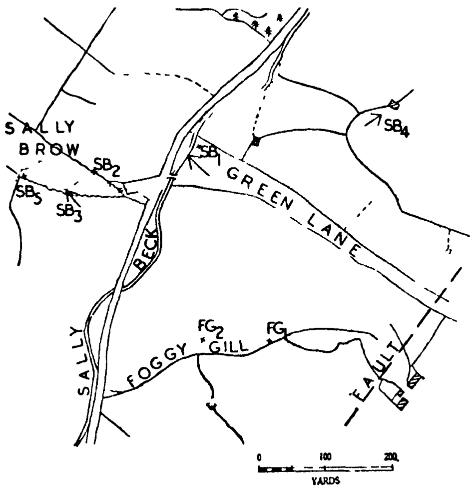
On p. 183, 1945, he states : " In Wales and Westmorland the Actonian includes the earliest deposits with *Tretaspis kjaeri, Phillipsinella* and other typical upper Bala fossils," but unfortunately gives no localities where these occur. As regards Wales (p. 186) he states that the Nod Glas is Marshbrookian and Actonian in age, and possibly also includes the Onnian. He also states that : " Locally, as at Bala, the Pusgillian includes a nodular limestone at the base "—this is presumably the Rhiwlas Limestone which contains the characteristic *Phillipsinella parabola* fauna normally associated with the Ashgillian as restricted by Bancroft (our Middle Ashgillian).

Since *Tretaspis kjaeri* occurs in the Actonian and Pusgillian, it must have existed during the Onnian in places where the conditions were suitable, and it would appear advisable to drop this form as a diagnostic zone fossil. The same has been claimed regarding *Tretaspis seticornis* by Lamont (1945). The evidence at present suggests that the *Phillipsinella parabola* fauna begins in the upper part of Bancroft's Pusgillian and continues through his Ashgillian. The *Diacalymene*

marginata beds on the evidence of our collections fall within his Pusgillian, since Bancroft places the *Dicellograptus complanatus* horizon of Girvan also in the Pusgillian.

In order to justify the claim that Marr's Calymene beds contain an Ashgillian and not a Caradocian fauna, the more important items of the fauna will now be considered.

Most of the specimens collected are from near Murthwaite, from the exposures between the Dent fault and the flanks of Wandle Fell in the valley of Sally Beck, the stream which comes down to join the



TEXT-FIG. 1.—Sketch Map of localities in Sally Beck, 6 miles N.E. of Sedbergh.

River Rawthey at Rawthey Bridge. Probably the beds are not more fossiliferous here than elsewhere in the district, but they are well exposed, particularly on Sally Brow, and here they are weathered to a state which makes collecting easy.

Most of the main exposures lie more or less on the same horizon, but in Foggy Gill it is probable that rather lower beds crop out, but these still yield the same fauna, as far as has been ascertained.

The rocks are all calcareous mudstones, dark leaden grey with blue hearted limestone nodules when fresh. They weather to a snuff-brown mudstone with rotten stones. The fresh rock is useless for fossil collecting.

The fauna is essentially a trilobite-brachiopod one with rare cystid plates and polyzoan remains in some bands. Marr gives his list on p. 7 (1913), mentioning 25 forms.

Of the trilobites which received specific determination, only *Cybele verrucosa* and *Homolonotus sedgwicki* might be considered more

Caradocian than Ashgillian in type, but the first of these appears to have been based on a single pygidium and specific determination of *Cybele* pygidia is generally open to doubt ; moreover, the *verrucosa* group of *Cybele* is in need of revision. The *Calymene* has been shown by Shirley to be quite distinct from the Caradocian forms. Amongst the brachiopods, nearly all the forms are either well known Ashgillian species, like *S. ruralis*, or are found in the Lower Drummuck horizon. The following list has been drawn up from the collections made to date :—

	General Distribution in Calymene *Beds.*
Acidaspis cf. *asteroidea* Reed	fc
Ampyx sp.	o
Calymene (*Diacalymene*) *marginata* Shirley	vc
Cheirurus octolobatus McCoy	o
Cybele loveni Linn.	c
Cybele verrucosa (auct.)	fc
Proetus sp.	o
Pterygometopus sp.	fc
Sphaerocoryphe cf. *thomsoni* Reed	o
Tretaspis kjaeri Størmer	c
Brachyprion matutinum Lamont	o
Christiana tenuicincta (McCoy)	o
? *Dalmanella* (s.l.) *federata* Reed	o
Fardenia scotica Lamont	vc
Glyptorthis sp.	o
Glyptorthis crispa (McCoy)	fc
Leptaena rhomboidalis Wilckens	c
Nicolella aff. *actoniae* (Salter)	o
Onniella aff. *bröggeri* Bancroft	fc
Platystrophia aff. *biforata* (Davidson *non* Schlotheim)	o
Plectorthis thraivensis ? Reed	o
Sampo ruralis (Reed)	fc
Skenidioides aff. *lewisi* (Davidson)	c
Sowerbyella sladensis Jones	c
Sowerbyella thraivensis (Reed)	vc
Stropheodonta bilix Lamont	o
Strophomena aff. *valens* Reed	o

o = occurs
fc = fairly common
c = common
vc = very common

Notes on some of the Fauna

Calymene (*Diacalymene*) *marginata* Shirley.—Over 50 good cranidia have been collected. Great variation in size from tiny specimens of which the glabella is not more than 4 mm. long to specimens measuring 12 mm. The majority, however, are about 8 mm. The ornamentation of the shell of the cephalon is seen in well-preserved specimens to be finely granulate all over, otherwise little is to be added to Shirley's description.

Cybele loveni Linn.—The next most plentiful trilobite is a *Cybele*, which is near *C. loveni.* The form *C. rugosa* is also closely related and appears to be separated only on the grounds of more nodules on the central part of the axis of the pygidium.

Cybele verrucosa Dalm.—This species appears to have been interpreted rather widely. The forms we have referred to this species are all rather badly distorted, but appear to be similar to specimens listed as *C. verrucosa* by Marr, from the *Phillipsinella* beds of Cautley. A specimen from Bwlch-y-gaseg in the British Museum (No. 48647), also presumably Ashgillian in age, is apparently the same species.

Tretaspis kjaeri Størmer.—Lamont has commented on the Tretaspids from this horizon and has noted that they agree with *T. kjaeri* except in not showing reticulation—most of the specimens in our collection do not show reticulation—but one specimen, Fig. 7, shows a marked reticulation and is otherwise similar to the rest of the Tretaspids.

Amongst the brachiopods a number emphasize the close comparison with the Lower Drummock beds, particularly the abundance of *Fardinia scotica*, a few specimens of *Stropheodonta bilix* and a geniculate variety of *Brachyprion matutinum.* Other typical Ashgillian brachiopods, such as *Sampo ruralis* and *Sowerbyella thraivensis* and *Leptaena rhomboidalis* of a stage of development similar to var. γ of Reed, conform with an Ashgillian fauna. On the other hand, Dalmanellids (s.l.), which are so important in the Caradocian, are represented only by a derivative of *Onniella bröggeri* which is distinct from its precursor in the absence of pallial sinuses and in the stronger convexity of the valves. When comparison of the brachiopods is made with those of the Lower Drummuck of Girvan, it can be said that as far as development of the internal structures is concerned, all the evidence points to a virtual contemporaneity of the faunas, but that in general the Cautley brachiopods are rather larger and thinner shelled than those from the sandy Lower Drummuck beds and this should probably be attributed to the more muddy environment at Cautley rather than any difference in age.

EXPLANATION OF PLATE

1*a*. *Cybele verrucosa* (auct.) cephalon. S.B.1. Sedg. Mus. No. A28853.
1*b*. Restoration.
2*a*. *Calymene* (*Diacalymene*) *marginata* Shirley. SB3. A28854.
2*b*. Ditto. SB1. A28855.
2*c*. Two cephala and two pygidia. Ditto. SB4. A28856–9.
3*a*. *Cybele loveni* Linn. cephalon. SB1. A28860.
3*b*. Restoration.
4. *Acidaspis* cf. *asteroidea* Reed cephalon. SB3. A28861.
5*a*. *Pterygometopus* sp. cephalon. SB3. A28862.

5*b*. Restoration.
6*a*. *Cheirurus octolobatus* McCoy cephalon. SB4. A28863
6*b*. Ditto. Pygidium. SB4. A28864
6*c*. Ditto. Restoration of cephalon.
7*a*. *Tretaspis kjaeri* Størmer, cephalon. FG2. A28865.
7*b*. Ditto. Impression of cephalon showing reticulate ornament. FG2. A28866.
8*a*. *Fardinia scotica* Lamont, internal cast of dorsal valve. SB3. A28867a.
8*b*. Ditto. External cast of same. A28867b.
8*c*. Ditto. Diagram of ribbing pattern.
8*d*. Ditto. (X3) Details of brachidium.
9*a*. *Brachyprion matutinum* Lamont, ventral valve. SB3. A28868.
9*b*. (X2) Ditto. Outline drawing.
9*c*. (X2) Ditto. Longitudinal section.
9*d*. (X2) Ditto. Ribbing pattern.
10*a*. *Stropheodonta bilix* Lamont. SB5, external cast of ventral valve. A28869.
10*b*. Ditto. Internal cast of same.
10*c*. (X2) Ditto. Ribbing pattern.
10*d*. (X3) Ditto. Details of ventral umbo.
11*a*. *Onniella* aff. *bröggeri* Bancroft, dorsal valve, internal cast. SB1. A28870.
11*b*. Ditto (X4). Details of brachidium.
12. *Sowerbyella thraivensis* (Reed), dorsal valve, internal cast. SB3. A28871.
13. *Sowerbyella sladensis* Jones, ventral valve, internal cast. SB3. A28872:
14. *Sampo ruralis* (Reed), ventral valve, internal cast. SB2. A28873.

All specimens from the *Calymene* beds of Sally Beck, Cautley.
Figures natural size except where otherwise stated.
SB = Sally Brow. FG Foggy Gill

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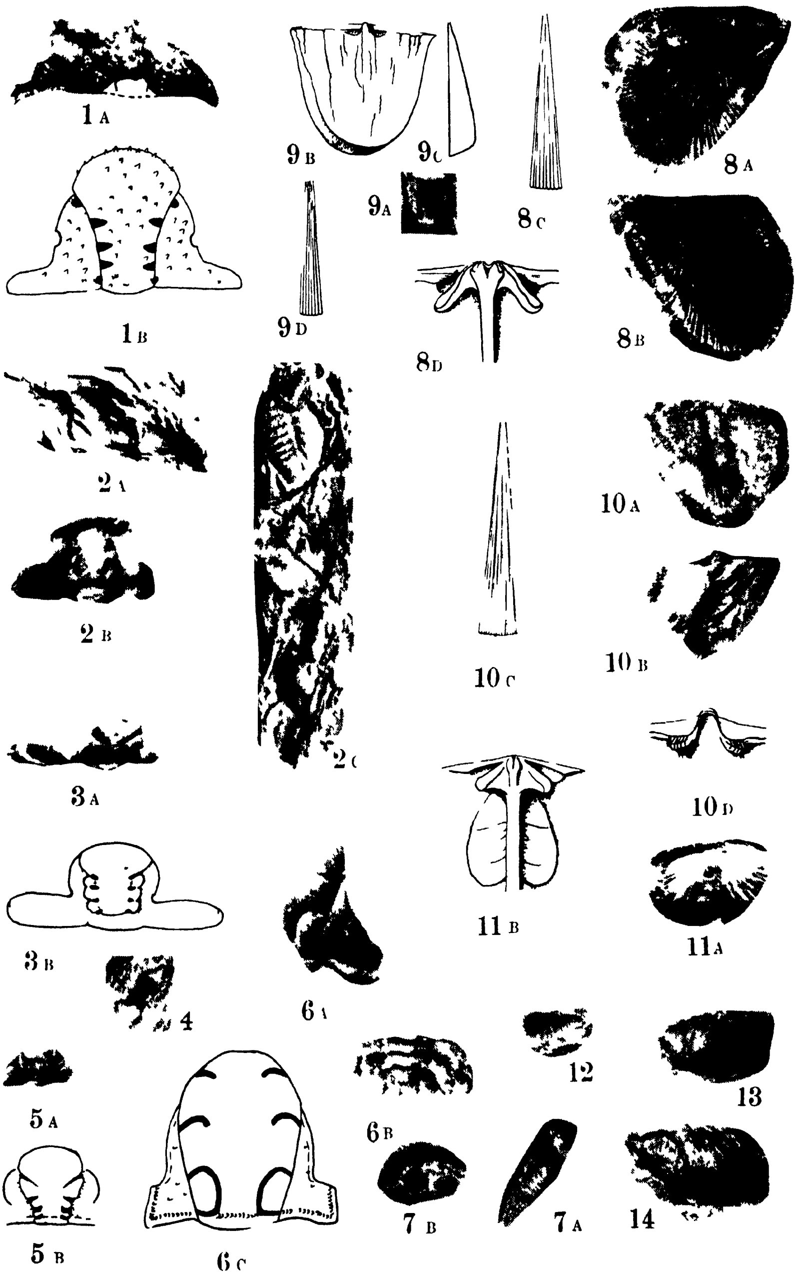

FOSSILS FROM THE CALYMENE BEDS, CAUTLEY.

Dolomite Contact Skarns of the Broadford Area, Skye : A Preliminary Note

By C. E. Tilley

The metamorphism of the Durness dolomite horizons in the aureole of the Beinn an Dubhaich granite of Skye has long provided one of the best known examples of dedolomitization and progressive thermal metamorphism of siliceous dolomites recorded in the literature. Harker's study (1904) concerned itself primarily with assemblages regarded as derived without notable accession of material during metamorphism and the occurrence of products of metasomatic origin at the contact of the granite has hitherto received but little notice in print. Yet as long ago as 1897, Geikie had written of this contact : " . . . the most abundant and interesting deposits are metalliferous. Fragments of a kind of ' gossan ' may be noticed all along the boundary line of the boss, and among these are pieces of magnetic iron ore and sulphides of iron and copper. The magnetite may be seen in place immediately to the south of Kilbride. A mass of this ore several feet in diameter sends strings and disseminated particles through the surrounding granophyre and is partially coated along its joints with green carbonate of copper " (Geikie, 1897, p. 384). It is of interest to note further that a record of " a mineral resembling humite " from this same contact is made in the Annual Report of the Geological Survey for 1896 (1897).

In Harker's later account (1904, p. 159) the only reference to products of the character referred to above is in a footnote to his description of the petrography of the Skye granites and granophyres, where he writes : " In one place only, 50 yards S.E. of the old ruined Manse at Kilchrist was found a lode of magnetic iron ore. It cuts the granite vertically bearing a little N. of W. and terminates at the junction of the granite with the Cambrian limestone."

The next recorded stage in the study of these ores is to be credited to Professor W. Q. Kennedy, who in September, 1940, while on other investigations in Skye, noted on the 6 inch Geological Survey maps of the Strath Suardal area by Harker and Clough a reference to a " magnetic iron ore lode " near the old Manse at Kilchrist. This occurrence is that referred to by Harker in 1904. Kennedy's examination of this outcrop led to the preparation of a preliminary report for the Geological Survey (dated 1st March, 1941, but unpublished). In this report (*Report on the Contact Metamorphic* (*Pyrometasomatic*) *Magnetite Deposits in the Cill Chriosd area, Isle of Skye*) the true significance of the skarn character of the iron ore was realized and a number of associated skarn silicates was recognized. The data of this report were made available to Home Ore Control of the Ministry

of Supply and eventually under the supervision of Mr. G. Duncan, Mr. S. H. U. Bowie, of Aberdeen University, conducted a magnetometer survey of the contact near Kilchrist. Further work brought to light a number of additional localities along the contact with strong indications of magnetic ore and on some of these exploratory trenching and excavation was carried out.

In the course of his field studies Professor Kennedy made an extended collection from the original Kilchrist and other localities on the northern border of the granite with a view to carrying out detailed petrological investigations. In this task he invited my collaboration and since 1943 several extended field visits to the principal localities have been made, partly in his company. With the laboratory investigations, however, Professor Kennedy has unfortunately not been able to continue, and at this stage when those studies are well advanced, I am glad to acknowledge my indebtedness to him not only for the opportunity to participate in the examination of these most interesting assemblages but also for his guidance in the field over the new contacts revealed in 1940–41, and for much fruitful discussion during the earlier stages of the work.

Mr. Bowie, whose work with the original magnetometer survey has already been noted, informs me he carried out these studies along with geological work at Kilchrist in December, 1940, and February, 1941, and that he had determined the presence of a mineral of the humite group in the skarn rocks at that locality. His further studies were interrupted at the beginning of 1942 by war service and finally discontinued in 1946. The results of his work at Kilchrist will, I hope, soon be made available.

Recent reference (Tilley, 1947) to the dolomite contact skarns of the Broadford area has been made in the description of cuspidine, an important constituent in a group of these assemblages, an example of which has been figured (*loc. cit.*, p. 92).

In the present note a brief statement on the assemblages met with in the skarns will be made, a detailed account of the numerous parageneses being deferred to a later time.

Here is presented mainly the record of the chief minerals of the skarns. The skarns may be divided broadly into two groups.

Group I.—Skarns at the immediate contact characterized by minerals stable with free silica—grossularite, wollastonite (and its solid solutions), clinopyroxenes (both diopside and hedenbergite) and plagioclase. These are derived by silication of the dolomite. The group is normally subdivided into distinct zones of contrasted composition and has a lateral extent of only a few inches across the vertical contact of granite and dolomite. The skarns may be bordered directly by metamorphosed dolomite or be followed by the ore skarns.

Group II.—Ore skarns often of considerably greater lateral extent following on the " limestone side " of the contact zone. These are especially characterized by the chief ore, magnetite together with the undersilicated minerals, forsterite, monticellite, minerals of the humite group (chondrodite, humite, clinohumite), and cuspidine. Clinopyroxene is often an important associated mineral. As a group these assemblages are associated with a boron-fluorine pneumatolysis and like the preceding group (Group I) are often multizoned with magnetite restricted to a particular zone. When the skarns of Group II replacing dolomite contain " sponge forms ", these have their own aureole of concentric metasomatic zones, the chert itself being ultimately wholly replaced.

Among the boron-bearing minerals of the skarns are ludwigite fluoborite, datolite, szaibelyite, and a new mineral, *harkerite*—a carbonate-borosilicate of calcium and magnesium.

These two groups of assemblages correspond broadly to two stages in the process of contact metasomatism, each group within itself containing secondary minerals—the first, the earlier, arising from directly local metasomatism at the granite contact, the second, later, and deriving by the passage of ore bearing solutions not directly local in origin, probably ascending from below and attacking preferentially the dolomite which has acted as an absorption apparatus. These ore skarns are, however, not confined to the dolomite against the skarns of Group I. Kennedy, in his report, drew attention to their development in " bays " or pockets of dolomite along the granite contact. Such " bays " at granite-limestone contacts have long been recognized as likely centres for active ore deposition : furthermore, in Skye the occurrence of pre-granitic dolerite dykes enclosed in the dolomites has provided contact surfaces which the ore solutions have used as channel ways. A striking example is that of Camas Malag where ore deposition has followed the contact of a pre-granitic dolerite within an embayment of dolomite. In their spatial relations to the skarns of Group I, however, the ore skarns accord well with the thesis of Umpleby (1916) that ore tends to occur on the " limestone side " of contact zones.

These then are the exomorphic zones. Against the inner zone the granite is modified but this endomorphic effect is traceable across the contact for only a short distance. The hornblende and biotite which are the normal ferromagnesian minerals of the Beinn an Dubhaich granite mass give place to clinopyroxene but the chemical nature of this mineral and indeed the petrographic character of the modified granite is found to be adjusted to the varying chemical composition of the inner exomorphic zone against which it abuts.

In the table adjoining a summary record of the metamorphic minerals

of the Durness limestone horizons in the aureole of the Beinn an Dubhaich granite is given. These are separated into three groups, those of the aureole beyond the skarn zones and the Groups I and II of the skarn zones as already briefly mentioned. The most abundant minerals of these two zones are indicated by asterisks.

In a later communication the paragenetic assemblages of these multizoned skarns will be dealt with in detail.

METAMORPHIC MINERALS DEVELOPED IN THE DURNESS LIMESTONE HORIZONS IN THE AUREOLE OF THE BEINN AN DUBHAICH GRANITE, SKYE

Aureole, beyond the Skarn Zones	Skarn Zones		
	Group I	Group II (Ore Skarns ; Boron and Fluorine Pneumatolysis)	
Talc	*Grossularite/Andradite	Magnetite*	Bornite
Tremolite	Wollastonite* and solid solutions	Diopside*	Chalcocite
Forsterite	*Diopside/Hedenbergite*	Forsterite*	Covellite
Diopside	Spinel	Monticellite*	Chalcopyrite
Periclase	Plagioclase*	Cuspidine*	Azurite, Malachite
Wollastonite (rare)	Vesuvianite	Fluor	Pyrite
Spinel	Xanthophyllite	Chondrodite*	Zincblende
Grossularite (rare)	Phlogopite	Humite	Galena
Brucite	Orthite	Clinohumite*	
Serpentine	Clinozoisite/Epidote	Ludwigite	
Chlorite	Prehnite	Fluoborite	
Hydromagnesite	Apophyllite	Szaibelyite	
	Pectolite	Datolite	
	Xonotlite	Harkerite	
		Grossularite/ Andradite	

Most abundant skarn minerals.

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Notes on the Geology of Killary Harbour

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Introduction

The Rosroe Peninsula, on the south side of Killary Harbour, Co. Galway, is formed of the Rosroe Grits, mapped by the Geological Survey of Ireland (1875) as " Lower Silurian ". Kilroe (1907) in a rapid revisionary survey of Galway and Mayo, described the succession on Rosroe as inverted (op. cit. p. 154, n. 3) :—

" Mr. McHenry informs me that the fossils (graptolites) on the south side are indicative of Upper Llandeilo, while those on the north side are Lower. This being the case, the order of the beds is inverted, as they dip northerly."

Carruthers and Maufe (Muff) (1909), on fossil evidence, determined the age of shales in the grit series as Upper Arenig, but made no observations on the attitude of the beds nor on the nature of their faulted boundary against Upper Silurian rocks.

This communication is intended to remove any misconceptions which may exist concerning the attitude of the Rosroe Grits, to draw attention to the conditions under which they were deposited, and to record some observations on the nature of the Salrock fault which bounds them to the south.

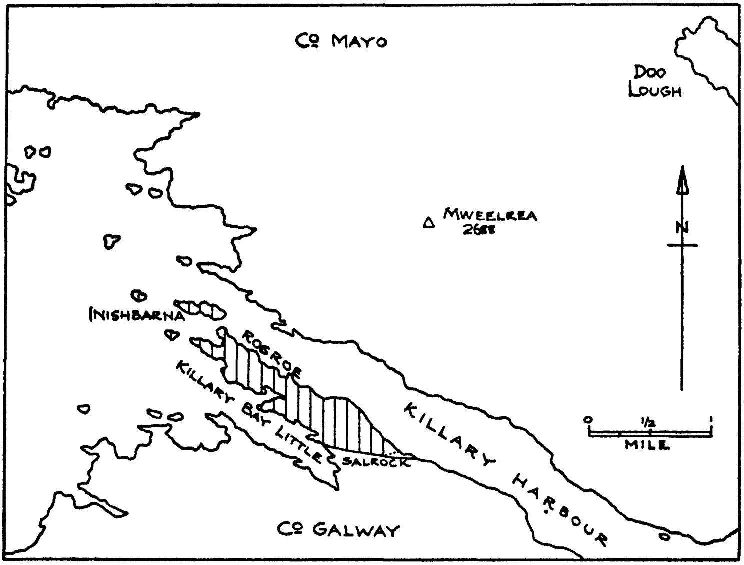
The investigations were carried out as a reconnaissance survey in 1947 when the succession was followed down to the contact between the Owenduff series (Upper Llandovery and Wenlock) and the Connemara Schists, the sequence established by Carruthers and Maufe being accepted provisionally. One day was spent searching for fossils in the Rosroe Grit Series but nothing was found and further time could not be spared on this occasion. It is hoped in the future to describe more fully both this area and the coast sections to the north and west of Killary Harbour, together with the offshore islands.

The Rosroe Grits

The Rosroe Grits are typically coarse grey or greenish sandstones, weathering pale grey with prominent white rounded grains of quartz. Immediately to the north of Salrock Pass, they form massive beds up to 20 or 30 feet thick, without any signs of bedding planes. Further on to the peninsula, pebble-beds containing rounded and angular quartz and chert pebbles are common. Each pebble-bed starts suddenly, is coarsest at the bottom and grades upwards in the direction of dip into coarse grits, fine grits, and sandstone within 2 or 3 feet. This sequence

may be repeated many times, up to ten separate rhythms being counted in a single outcrop. Some of the coarse beds of the grits show truncated foreset bedding. The Grits may end suddenly and be replaced by 10, 20, or even 30 feet of finely banded and bedded coarse sandy mudstones in which lenticular flaggy bands occur up to 6 inches thick.

Half way along the peninsula, on the northern shore, a 30-foot boulder-bed occurs, containing well-rounded boulders up to 2 ft. 6 in.



TEXT-FIG. 1.—Vertical ruling = outcrop of Rosroe Grits.

in diameter. The boulders consist of a pink granitic rock, mica- and quartz-schists, red jasper, grits indistinguishable from the Rosroe Grits, and numerous basic igneous rocks. It is interesting to note that the jasper is quite indistinguishable in hand specimen from the jaspers of Arenig age associated with the pillow lavas south of Lough Nafooey (Gardiner and Reynolds, 1914).

The boulder-bed is underlain by impersistent coarse grits resting on sandy mudstones from which they are separated by an undulating erosion surface. When the boulder-bed is traced westwards it is found to thin out rapidly and in a few hundred yards it disappears, being replaced by normal sandstones under which no sign of an erosion surface remains.

On the Island of Inishbarna, at the top of the succession, a great thickness of boulder-beds occurs containing well rounded boulders

up to 4 feet in diameter. Under these boulders a coarse grit overlies another erosion surface and at the west of the Island fills a wash-out in banded mudstones. The base of this grit is clearly ripple-marked at several points.

The Inishbarna boulder-beds continue to the northern shore of the island with no sign of ending, and show a certain regularity in their deposition. Beds several yards thick are separated by thinner bands of grit, but in neither is any grading discernible, the boulders beginning and ending suddenly. Occasional large boulders occur within the grits. The total thickness of the exposed series is about 350 feet.

The dip of all the beds on Rosroe peninsula is remarkably constant, varying at the most between 50° and 60° to the N.N.E. The northern coast approximately follows the strike. Structurally the beds appear to form part of the steep southern limb of the Mweelrea Syncline, the total thickness exposed being in the region of 3,000 feet.

Conditions of Deposition

There appears to be a definite major rhythm in the sedimentation of the Rosroe Grit series. Several hundred feet of coarse grits and graded pebble-beds are usually followed by an alternating series of flaggy mudstones and sandstones, the mudstone bands becoming more frequent higher in the succession. These are followed by an erosion surface on which rest more coarse grits and pebble- or boulder-beds. Superimposed on the major rhythm are the minor rhythms of the graded pebble-beds and the banding of the mudstones.

The whole sequence appears to have been deposited in shallow water and extremely rapidly. The changes in lithology may be attributed to variation in the level of the land supplying the detritus rather than to changes in depth of water. Although some of the mudstones could have been deposited in deeper water they are usually followed by grits or boulder-beds which rest on an erosion surface. The boulder-beds probably represent an actual emergence of the area of deposition. The rapidity with which one of them thins to nothing suggests a channel and it is undoubtedly underlain by an erosion surface which is absent close by.

There can be no doubt about the order of deposition, and any suggestion that the sequence is inverted is quite incorrect. The true order is shown by the following evidence :—

(1) The perfect examples of graded bedding which occur at intervals throughout the succession.

(2) The channelling and washouts cutting down into many of the mudstone beds.

(3) The ripple marking on the underside of the grit bed on Inishbarna.

(4) The current bedding sometimes seen in the coarse grits.

EVIDENCE OF SHORE-LINE

To the north of the Mweelrea syncline, in the neighbourhood of Doo Lough, highly cleaved green slates with subordinate grit bands are known to occur. These beds are reported to contain the same graptolite assemblage as the Rosroe Grits and are considered to be of the same age (Carruthers and Maufe, 1909). It thus appears that at least during the Lower Ordovician there was a land mass undergoing continued uplift lying in a general southerly direction from the Rosroe area. That this shore-line was relatively close is shown by the extreme coarseness of the boulder- and pebble-beds, and that it was roughly parallel to the present strike of these beds is suggested by the similar lithology of the contemporaneous Leenane Grits which outcrop some three miles to the east.

It is of interest to note that there is evidence of a similar shore-line during the middle Silurian. Two miles to the south the Owenduff Series, with a boulder-bed near the base, rests unconformably on the Connemara Schists (Wager, 1939).

THE SALROCK FAULT

The line of dislocation of which the Salrock Fault has generally been assumed to form a part is described by Wager (1939) as a line of unknown structural type but great importance. Bailey and Holtedahl (1938) make it coincide approximately with their continuation of the Southern Boundary Fault of the Midland Valley of Scotland.

Along the Pass of Salrock the fracture is traceable for about 1,200 yards and forms a strong feature on the north side, where an almost vertical cliff of Rosroe Grit stands up as a wall overlooking the area of the Salrock Slate Series, south of Killary Bay Little. At the foot of the cliff a deep depression runs along a 15 feet belt of smash and distortion and a steep slope of Salrock Slate rises sharply from the fault line, reaching a height of 728 feet above O.D. 1,200 feet from the fault, a net rise of some 570 feet.

At the head of Killary Bay Little the fault runs along a beach platform for 50 yards before passing out of sight below sea-level. Here the cleaved, flaggy mudstones of the Salrock Series, normally dipping steadily northwards, are strongly deformed about approximately vertical axial planes, and slabs and lenses of Rosroe Grit are caught up in a complex system of drag-folds and slices. Large-scale grooving, dipping 28° S.E. along the fault-plane, is seen on the grit beds north of the break and horizontal slickensiding occurs again in the grits, just before the deformed belt runs into the sea.

No general alteration of dip is seen in the grit series close to the fracture except at the eastern end of Salrock Pass where a reduction is

seen from the normal 50–55° to 28° without any change in direction. At the eastern end the fault apparently divides or is joined from the north by another fault at an angle of 45°, the beds in the acute angle between them being badly smashed and almost completely covered by peat and drift.

From this evidence it is difficult to develop a satisfactory working hypothesis of even the local nature of the fracture, and clearly much work is required before a wider theory can be developed. Four points may, however, be emphasized :—

(1) At least the latest movement along the fault shows a considerable horizontal component, although the total vertical throw must also be very great.

(2) Simple low-angle thrusting is probably not present.

(3) Although the Salrock fault must have a considerable throw, it appears unlikely that it constitutes the main line of regional dislocation. This is more likely to follow the line of Killary Harbour, which may well be a fault-line feature.

(4) A straightforward comparison with the Midland Valley Southern Boundary Fault is hardly justified. At Girvan, for example, a northerly Lower Palaeozoic shore-line is coupled with downthrow to the north, whereas here a shore-line to the south is followed by faulting with effective downthrow also to the south.

Acknowledgments

We are grateful to Professor W. B. R. King for the allocation of grants from the Shell Scholarship and Marr Memorial Funds towards the cost of this reconnaissance, to Dr. D. W. Bishopp, Director of the Geological Survey of Ireland, for help in the planning stage, and to Dr. R. M. Shackleton for discussion of various problems on the ground.

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Some Shropshire Ordovician Graptolites

By O. M. B. Bulman
(Sedgwick Museum)

DURING a recent excursion to Shropshire ,members of a Sedgwick Club party collected a number of graptolites, and some of these, supplemented by specimens collected by the writer many years ago, now seem worth recording.

1. Rorrington Stage

Collections from the flaggy shales of the Rorrington Stage were made at a bend of the brook in Spy Wood, 375 yards above (E.S.E. of) its junction with Aldress Dingle. *Nemagraptus gracilis* and *Leptograptus validus* were collected in abundance, together with *Cryptograptus tricornis*, etc., but the interesting find was a synrhabdosome of a *Climacograptus* shown in Text-fig. 1*a*, apparently referrable to *Cl. modestus* Ruedemann. This is, I believe, the first record of a graptolite synrhabdosome from Britain and the first British record of this species, though it has possibly been previously listed as *Cl. scharenbergi*, which it closely resembles.

CLIMACOGRAPTUS MODESTUS Ruedemann

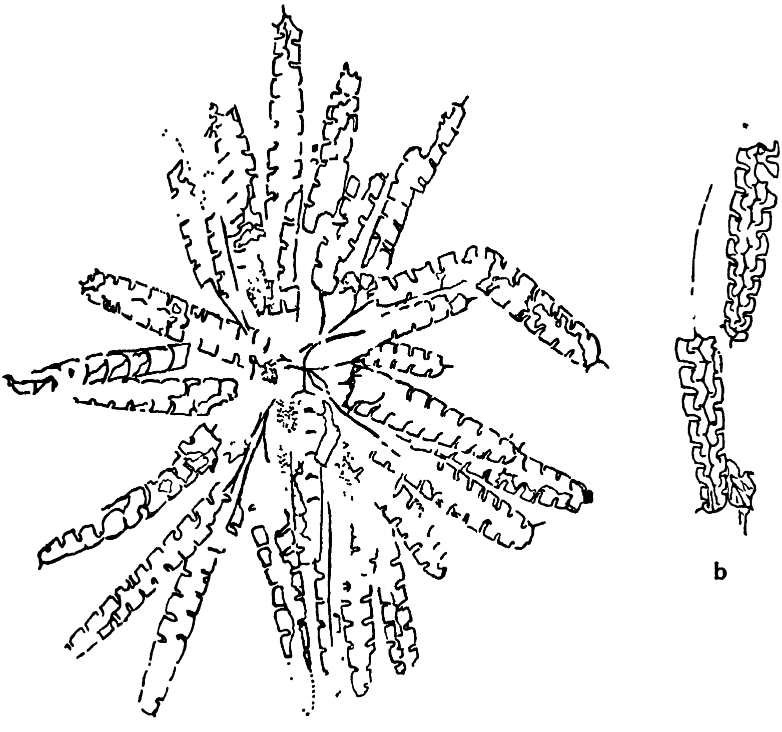
Text-fig. 1*a*, *b*

1908 *Climacograptus modestus* Ruedemann, *N.Y. State Mus., Mem.* 11, p. 432, pl. 28, fig. 30.
1947 *Climacograptus modestus* Ruedemann, *Geol. Soc. Amer., Mem.* 19, p. 432, pl. 73, figs. 32–46.

Synrhabdosome small, greatest diameter slightly less than 2 cm., composed of about 26 immature colonies mostly 5–6 mm. in length. As in the examples figured by Ruedemann (1947, pl. 73) there is no central disc or float, the virgulae forming a branching and interlacing tangle. The synrhabdosome is poorly preserved and the characters of the species are better seen in other specimens (text-fig 1*b*).

In the characters of the thecae and the zig-zag septal groove, the species closely resembles *Cl. scharenbergi*, from which it is distinguished principally by the more close-set thecae and the shape of the rhabdosome. The thecae here are commonly 9 in the first 5 mm., as compared with 7 in *scharenbergi* ; Ruedemann gives the number in *modestus* as 14–18 in 10 mm., commonly 16. The rhabdosome is slender, 1·0–1·2 mm. broad, almost parallel-sided, attaining its maximum width within the space of the first few thecae. The sicula end has altogether a more square-cut, blunt appearance than in

scharenbergi, where the rhabdosome tapers steadily to an almost pointed sicular extremity.



a b

TEXT-FIG. 1.—*Climacograptus modestus* Ruedemann × 5. Rorrington Flags, Spy Brook, Shropshire.
(*a*) Synrhabdosome (collected by Mr. T. G. Miller); the colonies are badly preserved and completely flattened.
(*b*) Two better-preserved rhabdosomes, in slight relief, showing septal groove, thecal characters, and shape of the proximal end.

2. Aldress Stage

On this occasion, collections were made from the lower part of the Aldress Shales in Spy Brook, about 180 yards above (E.S.E. of) its junction with Aldress Dingle. This may be the horizon referred to by Watts (*Proc. Geol. Assoc.*, xxxvi, 1925, p. 340) as "shales with *Dicranograptus*" and is several hundred feet below the well-known *Dictyonema* horizon.

DICRANOGRAPTUS cf. RAMOSUS var. SPINIFER Lapworth MS.

Text-fig. 2*a*

Cf. 1904 *Dicranograptus ramosus* var. *spinifer* Lapworth MS., Elles and Wood, *Mon. Brit. Grapt.* (Pal. Soc.), p. 176, pl. xxiv, figs. 8*a–c*.

Cf. 1908 *Dicranograptus spinifer* Ruedemann, *N.Y. State Mus., Mem.* 11, p. 330, pl. 22, pl. 23, figs. 2, 3.

Cf. 1947 *Dicranograptus spinifer* Ruedemann, *Geol. Soc. Amer., Mem.* 19, p. 396, pl. 66, fig. 25, pl. 67, figs. 20–23.

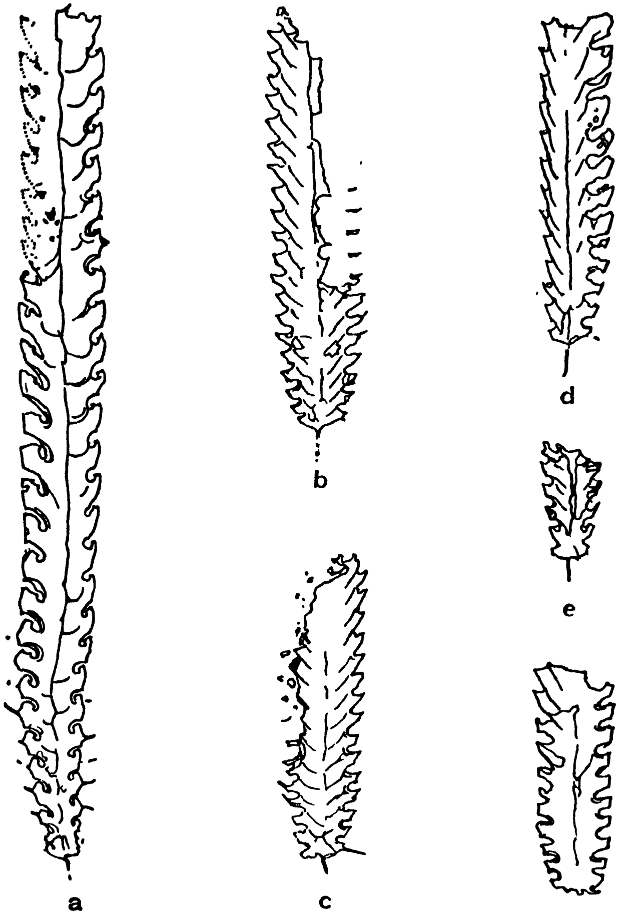
The variety was erected by Lapworth for forms of *D. ramosus* possessing a long, often fusiform, biserial portion (comprising some 30 thecae on either side) and spinose thecae. Ruedemann raised it to specific rank and described a variety of it, *D. spinifer* var. *geniculatus*,[1] later (1947) recognized as synonymous with Gurley's *Dicranograptus arkansasensis.* Ruedemann noted that the New York *D. spinifer* differed from the British forms in having more widely spaced thecae (8–9 in 10 mm.) and spines on not more than the first dozen thecae ; *D. spinifer* var. *arkansasensis* agrees with the British forms in having the entire biserial portion spinose, but differs in its geniculate uniserial branches.

The specimen from Spy Brook has closely-set thecae (11 in 10 mm.) but resembles the American *D. spinifer* in bearing spines on the proximal thecae only ; the first seven thecae on each side are clearly spined and there are traces of spines related to the 10th and 14th thecae. Restriction of spines to the proximal part of the biserial portion does not seem to be entirely preservational, and in this feature the form is not identical with previous British records.

Reference may also be made here to a specimen of a geniculate *Dicranograptus* collected on a mapping party in 1934 from the *Mesograptus* Shales of Oakwood, Pontesford. The proximal end is broken, but 11 mm. of the biserial portion remains, and is slightly fusiform, probably not exceeding 15 mm. when complete. All the thecae except possibly the last three on each side are furnished with stout spines and the specimen may be referred with reserve to *Dicranogr. ramosus* var. *spinifer.*

In Britain, *D. ramosus* var. *spinifer* ranges from the *N. gracilis* zone to that of *C. wilsoni* and is essentially a Glenkiln species ; the American *D. spinifer* is typically Normanskill, with a later Canajoharie mutation.

[1] A tendency to the production of geniculate forms in *D. ramosus s. str.* was noted by Elles and Wood with the comment : " Should the discovery of more examples prove that this form was a permanent one, it would be worthy of a varietal name " (1904, p. 175).



TEXT-FIG. 2.—Graptolites from the Aldress and Harnage Shales × 5.
(*a*) *Dicranograptus* cf. *ramosus* var. *spinifer* ; proximal end preserved in semi-relief. Aldress Shales, Spy Brook (coll. 1948).
(*b*), (*c*), (*d*) *Diplograptus multidens* ((*d*) preserved in three-quarter face view) from the Aldress Shales of Spy Brook (coll. 1948).
(*e*), (*f*) *Diplograptus multidens ;* two examples, etched from the shale with HF. Harnage Shales, Coundmoor Brook.

DIPLOGRAPTUS MULTIDENS (Elles and Wood)

Text-fig. 2*b–d*

1907 ***Diplograptus* (*Mesograptus*) *multidens*** Elles and Wood, ***Mon. Brit. Grapt.*** (Pal. Soc.), p. 261, pl. xxxi, figs. 9*a–d*.

The specimens here referred to this species are all of small size, scarcely exceeding a centimetre in length. From an initial width of

1·3 mm. (at the level of the aperture of th1²) they widen rapidly to between 2·1 and 2·5 mm. The thecae number 9–10 in the first 5 mm., decreasing to 7–8 in the second 5 mm.; those of the first 5 or 6 mm are typically amplexograptid, but the orthograptid characters are already manifest in the thecae of the distal 3 or 4 mm. The transition is quite sharp and seems to occur slightly earlier in the development of the rhabdosome than in forms from the typical Oakwood (Pontesford) locality. Spines are present on th1¹ and th1², and there is a conspicuous virgella.

GLYPTOGRAPTUS TERETIUSCULUS var. SICCATUS Elles and Wood

Text-fig. 3*a*

1907 *Glyptograptus teretiusculus* var. *siccatus* Elles and Wood, *Mon. Brit. Grapt.* (Pal. Soc.), p. 283, pl. xxxi, figs. 3*a–d.*

Several rhabdosomes referrable to this variety were collected by the writer many years ago from a locality in Aldress Dingle, 500 yards above (north of) its junction with Spy Brook. Though poorly preserved, they show well the thecal characters and tenuous periderm of this essentially Glenkiln form. From the same locality are to be recorded *Diplogr. multidens*, *Cryptograptus tricornis*, and a fragment of the biserial portion of a *Dicranograptus.*

ORTHOGRAPTUS TRUNCATUS (Lapworth) ?

Text-fig. 3*d*

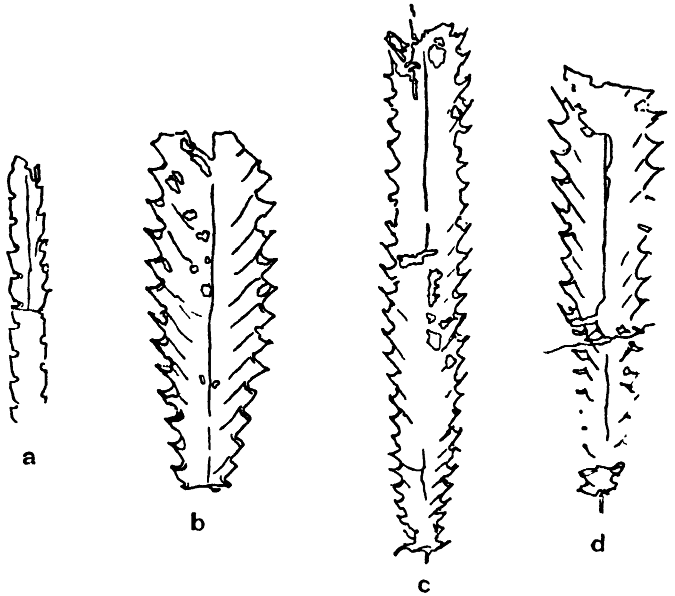
A specimen possibly referrable to this species was obtained at the same time as the last from what is probably a somewhat higher horizon in Aldress Dingle, 350 yards above its junction with Spy Brook. Length 11½ mm.; breadth at origin (th1² aperture) 1 mm., widening steadily to 2·5 mm. distally. Thecae rather obscure proximally, where the periderm has been weathered away, distally of *truncatus* type, overlapping ½ to ⅔ of their length, numbering about 14 in 10 mm.

3. Stratigraphical Conclusions

The Aldress Shales are, by common consent, regarded as the western equivalents of the Harnage Shales of East Shropshire, which have always been considered to be, in the main at least, of *Dicranograptus clingani* zone age. *D. clingani* itself has not been found in either group, but *Orthograptus truncatus* has been reported from both; it is recorded from the Harnage Shales in *Geological Survey Memoir, Shrewsbury District* (1938, p. 87), and from the Aldress Shales by Whittard (Elles *in* Whittard, *Proc. Geol. Assoc.*, xlii, 1931, p. 333). In correlating the Aldress Shales with the Zone of *Dicranograptus*

clingani, Whittard notes, however (*loc. cit.*), that "lower horizons may be represented".

The present record of *Diplograptus multidens*, together with *Glyptograptus teretiusculus* var. *siccatus* and *Dicranograptus* cf. *ramosus* var. *spinifer*, fully justifies Whittard's prediction just quoted and shows that the lower part at least of the Aldress Shales is considerably lower



TEXT-FIG. 3.—Graptolites from the Aldress and Harnage Shales × 5.
(*a*) *Glyptograptus teretiusculus* var. *siccatus*; fragment from the Aldress Shales of Aldress Dingle.
(*b*) (*c*) *Orthograptus truncatus* (Lapworth); two examples preserved in semi-relief from the Harnage Shales "near Coundmoor Quarry" (Sedg. Mus. A 19747).
(*d*) *Orthograptus truncatus* (Lapworth)? Aldress Shales of Aldress Dingle.

in the graptolite succession, corresponding probably to the zone of *D. multidens*. This statement is not supported by adequate fieldwork, but from what is probably higher in the sequence (unless the shales are disturbed) has been obtained a form (text-fig. 3*d*) which is perhaps referrable to *O. truncatus*, and this suggests the presence of something more nearly approaching the *D. clingani* zone. It is presumably from these higher beds that *O. truncatus* was recorded by Whittard.

Similarly, in the Harnage Shales, *Diplograptus multidens* (text-fig. 2*e*, *f*) has been obtained from an old collection of my own, not more precisely localized than "Coundmoor Brook". *Orthograptus*

truncatus is a not uncommon fossil (text-fig. 3*b*, *c*, and *Geol. Surv. Mem.*, *Shrewsbury Memoir*, p. 87), so that here again the inference is that the *D. multidens* zone is present below the previously recognized *clingani* zone.

Thus, it seems certain that the basal portion at least of both the Aldress and Harnage Shales is of much the same age as the geographically intermediate *Mesograptus* Shales of Pontesford ; and it may be noted that a single specimen of *Orthograptus truncatus* has been recorded (*Shrewsbury Memoir*, p. 92) from these *Mesograptus* Shales of the Oakwood (Pontesford) district.

On the Significance of Thermal Structure in the Scottish Highlands

By W. Q. KENNEDY

THE formation of a fold mountain chain is, essentially, a thermal phenomenon, as may be deduced from the internal locus of the forces involved, the frequent association of magmatic activity with orogenic movements, and the widespread thermal and regional metamorphism of the sediments within the deeper parts of the mountain belt.

In the study of mountain building processes, therefore, it is necessary to determine not only the general and detailed tectonic structure, but at the same time to investigate the thermal conditions within the orogenic zone. It is obviously impossible to effect direct measurements of temperature within a recent fold mountain system, and for our information on this subject we must turn to the more deeply eroded mountain roots, such as the Scottish Caledonides, where the minerals developed during orogenic regional metamorphism serve as recording thermometers, to measure the relative distribution of temperature.

This method depends for its application on a simple relationship, enunciated by Barrow (1893, 1912), more than fifty years ago, to the effect that, in rocks of appropriate bulk composition, advancing metamorphism is marked by the appearance in turn of certain critical index minerals. Barrow established the following succession of index minerals :—

clastic micas → digested clastic micas → biotite → garnet → staurolite → kyanite → sillimanite

as indicative of progressive metamorphism in rocks having the composition of normal argillaceous sediments, and was able to lay down on the map lines marking the point of entry of each successive new mineral index. Tilley (1925) substituted chlorite for Barrow's two clastic mica zones, and staurolite being of doubtful value as an index mineral, since it requires special formation conditions, the following index minerals are used in this paper :—

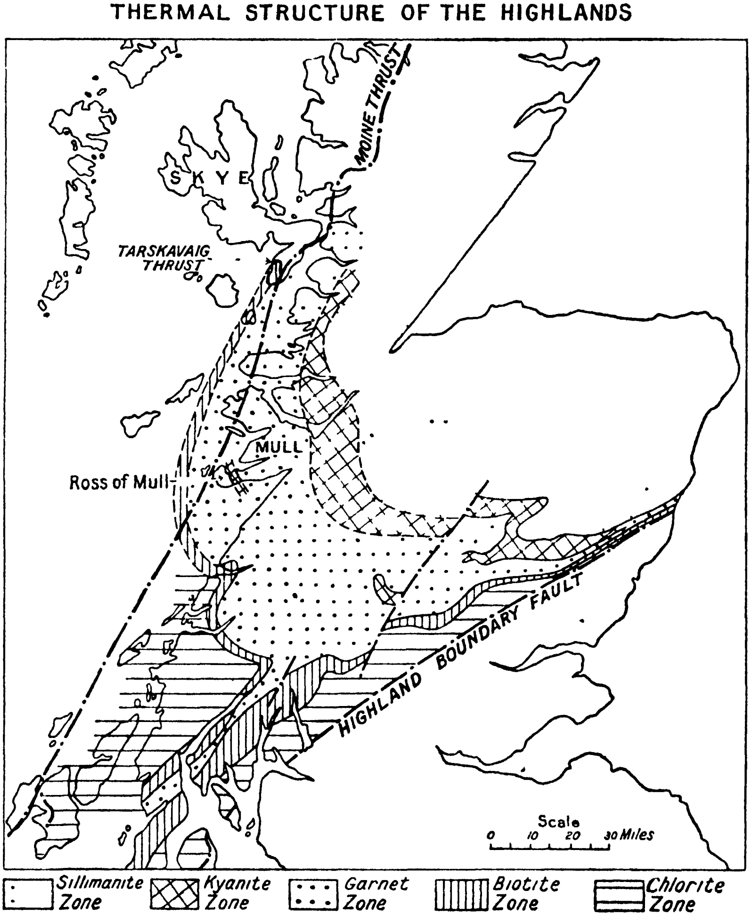
chlorite → biotite → garnet → kyanite → sillimanite

The zonal system established by such means provides a relative temperature scale which allows us to portray graphically the manner in which the temperature-pressure conditions have varied in response to advancing metamorphism.

This pioneer work, initiated by Barrow within the Southern and Eastern Scottish Highlands, was communicated in two papers published in 1893 and 1912.

Using similar methods, although apparently unaware of Barrow's

work, Goldschmidt in 1915 published a zonal metamorphic map of the Trondhjem region (Goldschmidt, 1915), and so confirmed the applicability of Barrow's zonal indices to regions other than those originally investigated. No further work of this nature was undertaken



TEXT-FIG. 1.—Thermal map of the Scottish Highlands. Based partly on zonal metamorphic maps by Barrow, Tilley, and Elles. Map corrected for 65 miles of lateral displacement along the Great Glen Fault.

in Scotland until 1923, when Bailey (1923), employing different mineral indices, published a zonal map of the South-West Highlands. In 1925, however, Tilley (1925) carried Barrow's zonal lines southward and westward over a considerable portion of Perthshire and Argyll, and subsequently, in collaboration with Dr. Elles, published a zonal

map covering the whole of the South-West Highlands up to the line of the Great Glen (Tilley and Elles, 1930). Later investigators have confined themselves mainly to detailed metamorphic studies of particular rock-groups within the areas already zoned, and it is only within recent years that the author has applied Barrow's methods to the Moine Schists lying to the north and west of the Great Glen (Western Inverness-shire and North-West Argyll). Further reconnaissance has also been carried out in certain critical regions of the Central Highlands, and, although large areas still remain unstudied, it is now possible to assemble the available results, and to obtain a generalized view of the thermal structure of the Highlands.

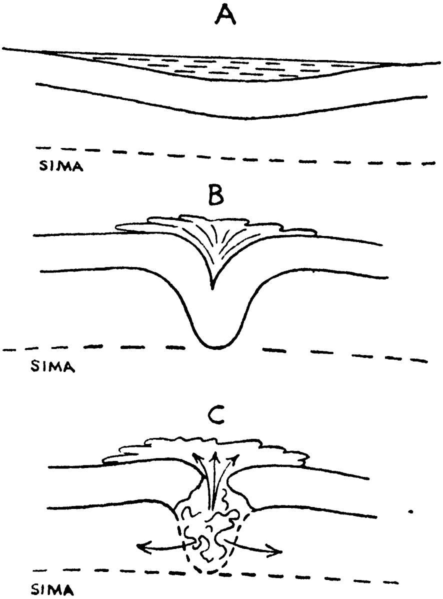
All the available data have been collected and are presented in the thermal map, Text-fig. 1. In constructing this map it has been necessary, in order to show the true relationships of the metamorphic zones, to effect a correction for the major 65 miles of lateral displacement along the Great Glen Fault. The Northern Highland block has consequently been restored to its original prefault position, and, when this is done, we obtain a picture of the thermal structure of the Highlands, which is arresting in its simplicity.

It must here be emphasized that the zonal boundaries (or *isograds*) as they appear on the map, represent the traces or outcrops of isothermal " *surfaces* ", which possess three-dimensional relationships. We may consequently refer to their structural disposition just as we may refer to the tectonic structure of the associated rocks. Having regard to this zonal map it is apparent that the thermal structure of the Highlands is essentially that of a simple *anticline of thermal " surfaces "*. The thermal anticline pitches to the south-west, and its axis is parallel to the axis of the main Caledonian folding. The high temperature core (sillimanite zone), emerges to the north-east, which consequently forms a region of culmination, whereas to the south-west, the pitch brings on successively lower temperature regions (kyanite, garnet, biotite, chlorite zones), and constitutes a thermal pitch depression. The axis of the thermal structure is disposed centrally, and the metamorphism is seen to die off towards the north-western and south-eastern edges of the crystalline Highland mass.

The development of this great thermal anticline is obviously not related to the surface tectonics of the region, but must, in view of its magnitude and simplicity, be related to some major element of basement structure.

The basement structure in question is considered by the writer to be that fundamental orogenic element, the " tectogen " or mountain " root ". The conception of the mountain " root " has been developed by Vening Meinesz (1934) to explain the remarkable strips of negative gravity anomaly which front the recently folded orogenic arcs of the

East and West Indies. These gravity anomalies are explicable only on the assumption that, along the particular lines concerned, the granitic crust carrying its superincumbent load of geosynclinal sediments has been buckled down into a sharp root-like isoclinal fold in response to orogenic pressure. Concomitantly the geosynclinal sediments themselves undergo folding and thrusting, with the development of the tectonic structures characteristic of orogenic deformation



TEXT-FIG. 2.—Diagram to illustrate the evolution of a "tectogene". A. Geosynclinal phase. B. Main Tectogenic phase. C. Disintegration of mountain "root".

(Kuenen, 1937; Hess, 1938). The major crustal fold or "root" is believed to penetrate downwards far into the "*sima*", and so comes to rest within a region of high temperature. Ultimate disintegration, melting, and dissipation of the "root" must eventually take place with at least partial upward migration of the remelted granitic material. It is to this uprising granitic material that we must ascribe the widespread injection and migmatitization of the folded rocks belonging to the deeper zones of the mountain chain, the regional metamorphism at yet higher levels, and the ultimate emplacement of batholithic granites.

The conditions are illustrated diagrammatically in Text-figs. 2 and 3. The upwardly arched and uprising *isothermal* "*surfaces*" marked

that Kuenen writes as though this synthesis is new. It is probably the most complete and balanced account yet made available, though the theory has surely long been assumed by many.

In " Submarine canyons and their formation " Kuenen first discusses the morphological data, then enumerates the hypothesis as to origin. Along with other subaerial explanations Shepard's detailed attempt to combine maximum possible glacial eustasy of 1,100 m. with a consequent isostatic uplift of the continental slopes of the order of 1,000 m. is rejected, particularly in view of the widespread distribution of canyons. Kuenen restates Daly's theory of turbidity currents supporting it by experimental work which is suggestive but not conclusive. This is combined with the idea of slumping of mudflows and landslides as an initial cause of and as an effect of downcutting by turbidity currents. These high density currents may also be initiated by offshore currents due to onshore waves (including tsunamis), especially when sea level was reduced 80–100 m. during the Pleistocene. At such a time much unconsolidated sediment would be within reach of wave motion and the continental slope. Some canyons are accepted as due to faulting, but artesian spring sapping is mechanically most improbable. The discussion could have been put together more concisely, but Professor Kuenen has already reduced a great bulk of literature for our convenience.

W. B. H.

BRITISH REGIONAL GEOLOGY. EAST YORKSHIRE AND LINCOLNSHIRE. By VERNON WILSON. *H.M. Geological Survey*. pp. iv + 92, with viii plates and 34 text-figures. London : Stationery Office, 1948. Price 2*s*. 6*d*.

This is the only one of the invaluable series of Regional Handbooks that was not published before the outbreak of war in 1939, and is therefore a first edition and as such worthy of somewhat extended notice. The delay in publication has had at least the advantage that the author was able from the beginning to incorporate the results of much work carried out in the last ten years, without the trouble of fitting it into a revised version like all the others. And it was no light task that he undertook. The geology of the region is complicated, with a remarkable amount of local variation, and the literature is enormous. North-East Yorkshire was quite definitely one of the cradles of stratigraphy, and William Smith lived there for many years. It is to be regretted that in the paragraph dealing with the heroic age no mention is made of the work of Young and Bird, which was published some years before that of Phillips, and in some points is distinctly better.

Among the recent work of first class importance in the region is the extensive boring campaign in search of oil, including the deep bores of Aislaby in Eskdale and another west of Bilsdale, which in the literature is vaguely described as in the Cleveland Hills. The first-named yielded much gas, but no oil, and ended in Permian salt-bearing rocks, with a 45 foot bed of polyhalite, unfortunately at a very great depth. Many bores in Lincolnshire also yielded interesting results, having touched Pre-Cambrian rocks in at least one place, besides many instances of Carboniferous strata, including some Coal Measures at great depths. The highly productive oil-field at Eakring in Notts, is of course outside the area here dealt with.

Dr. Wilson has been remarkably successful in making clear the extremely complicated story of the Jurassic and Cretaceous rocks, with their endless variations in thickness and changes of facies. He gives a full account of recent results obtained in work on the Blea Wyke beds and the Dogger, which cannot here be set out in detail.

Much attention is naturally given to structure, and particularly to the Cleveland and Market Weighton axes, which though parallel and not so very far apart, were so strangely different in their behaviour. The Cleveland uplift, which is of the Wealden type, with a syncline in depth, is not quite so simple as was formerly thought, being complicated towards its eastern end by two well-marked domes, one, based on Sleights Moor, being the reason for the Aislaby bore, and the other is cut in two by the coast at Robin Hood's Bay. Around Whitby there is a basin, which, as suggested by recent observations, is perhaps not quite so deep as supposed by Versey and by Lees and Cox. It is also doubtful whether the Whitby fault is as important as is generally stated.

Considerable emphasis is rightly laid on the importance of the hiatus between the Lias and the Middle Jurassic. It is also stressed, and not before time, that the name " Estuarine Series " for the Middle Jurassic of Yorkshire is a complete misnomer, as the whole is deltaic, in fact a miniature coalfield, with thin coal seams, seat earths, marine bands, fossil plants, and washouts, all complete. All this in a total thickness of some 700 feet of strata must mean considerable tectonic activity.

It would be possible to go on almost indefinitely quoting points of interest, but it must suffice to congratulate Dr. Wilson on having produced a most interesting and well-written account of an area which is classical in geology. Finally, it may be questioned whether it is really necessary in a work like this of a semi-popular character, intended largely for amateurs, to quote the authority for every fossil every time, especially since so very few of the original generic names still survive.

R. H. R.

AN OUTLINE OF THE GEOLOGICAL HISTORY OF SOUTHERN RHODESIA. By A. M. MACGREGOR. Geological Survey Bulletin No. 38. pp. 73. Price 2*s*.

The author of this Bulletin, the Director of the Geological Survey, says in his preface that he has made it short and simple, in the hope of interesting others besides geologists and miners, and has tried to avoid the use of unnecessary technical terms. It is written to accompany the new fourth edition of the general geological map of the country : it certainly reads very pleasantly.

The geology of Southern Rhodesia is very like that of the Union of South Africa ; that is to say, it is a typical example of the Gondwana succession, and therefore totally unlike anything in North-West Europe. It may be summed up as follows : basement granites, no doubt largely formed by granitization of sediments and igneous rocks, though some granites may be really magmatic, that is intrusive ; above this come several Precambrian systems in patches constituting the Gold Belts ; then the Karroo System, with valuable coals ; some Cretaceous near the Zambezi and some kimberlite pipes and, finally, the Kalahari Sands. It will be noticed that, as in the Transvaal and Orange Free State, there is no representative of the Cape System, which seems to belong to du Toit's Samfrau geosyncline and is the only known marine Palaeozoic in southern Africa.

The old and much altered rocks of the Gold Belts, which amount to the enormous thickness of 60,000 feet, are divided into three systems, Sebakwian, Bulawayan, and Shamvaian. Above these comes the Lomagundi System, 24,000 feet thick. The lower part of this, mainly lavas, is believed to be equivalent to the Ventersdorp of the Transvaal and the upper part with dolomite to the Transvaal System. Next comes the Umkondo, several thousand feet thick, correlated with the Waterberg-Matsap of the Union.

Perhaps the most interesting feature of the geology of the area is the Great Dyke, which is 320 miles long and from 3 to 6 miles wide. It points straight for the Bushveld Complex of the Transvaal, and the petrography is very similar, including even a layer with platinum. One cannot help feeling that the Great Dyke is essentially a rift valley which has somehow got filled up with a magma rich in chromium from a very deep layer of the earth.

The Karroo System is incomplete, with a gap in the middle, but it includes the valuable Wankie coalfield, with its interesting flora. No Dwyka is known in place, but some specimens collected many years ago by Molyneux in country not yet mapped are very like it.

The principal economic products are gold, asbestos, coal, and chrome ore, of which the first has so far been much the most important. The value to date has been about £158,000,000. R. H. R.

ORE GENESIS OF QUEENSLAND. By O. A. JONES. Presidential Address, Royal Society of Queensland, 1947. *Proc. Roy. Soc. Queensland*, vol. lix, No. 1, 91 pp. Brisbane, 1947.

The ore deposits of Queensland are of great economic importance as is shown by such well-known names as Mt. Morgan and Charters Towers, as well as the more recently developed Mt. Isa field. They also show many points of high geological interest. Hitherto, as pointed out at the beginning of this address, there has been no comprehensive account of them as a whole, although the literature is very large (ten pages of bibliography at the end of this publication).

In the classification here adopted, four metallogenetic epochs are recognized, as follows: Cloncurry Epoch, late pre-Cambrian; Herberton Epoch, late Devonian or early Carboniferous; Gympie Epoch, late Permian to Triassic; Maryborough Epoch, Upper Cretaceous.

It is only in the north-west of the State that pre-Cambrian metallogeny is extensively developed, and its age is definitely fixed by the fact that the mineral deposits are overlain by fossiliferous Cambrian strata, with trilobites (*Redlichia*, highest Lower Cambrian). The Mt. Isa deposits show considerable resemblance to Broken Hill, some 800 miles farther south, and are more explicitly classed as older Proterozoic. The metals are Ag, Pb, Zn, Cu, occurring as replacements in a belt of shale 9,000 feet thick, over a length of 5 miles and a width of 2,000 feet.

Farther east the deposits of the Herberton Epoch and area show many points of geological interest, especially the remarkable structures called pipes, with their concentrations of tin, tungsten, molybdenum, and bismuth, associated with highly siliceous granites.

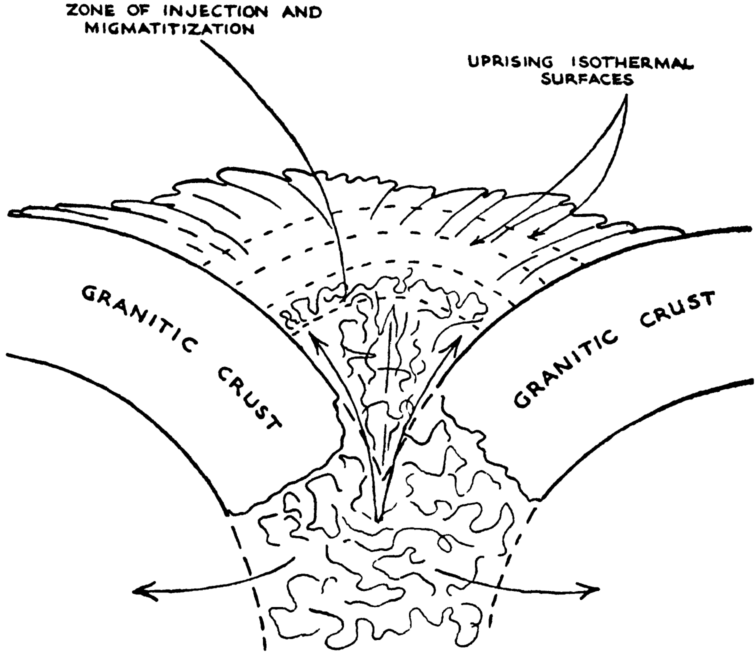
It was for long believed that the Gympie Epoch, late Permian to Trias, was the most important in the mineralization of Queensland, but it is here shown that several occurrences usually assigned to it are really older and belong to the Herberton Epoch. The Gympie deposits are very definitely associated with the east coast, the region of the Tasman geosyncline, and perhaps once extended into the lost part of the continent to the east.

The Maryborough Epoch, of late Cretaceous age, here first defined, is of minor importance, being confined to a small area in the extreme south-east of the State.

The address concludes with a short general survey of metallogenetic epochs in the other States of the Commonwealth and in neighbouring lands, viz. Papua and New Caledonia. Finally, it is made clear that all the mineralization of Queensland is associated with periods of orogeny and granitization.

R. H. R.

by outwardly decreasing zones of regional metamorphism will consequently reflect in their structural disposition the symmetry of the underlying tectogenic " root ". We may deduce, therefore, that the metamorphism of the Scottish Highlands is related to such a major



TEXT-FIG. 3.—Diagram to illustrate the relationship of metamorphic zones (isothermal surfaces) to processes connected with the disintegration of the tectogenic " root ".

downfold in the crystalline basement, and that the marginal thrusting along the north-west and south-east margins of the region constitutes marginal shearing along the edges of the crystalline mass in response to post-crystalline pressure.

It is interesting to consider that essentially similar conditions can be postulated for the Norwegian sector of the Caledonian mountain range. We may reflect that Goldschmidt, in his study of the Caledonian deformation of the pre-Cambrian basement in Southern Norway (Goldschmidt, 1912), has adduced geological evidence of a sharp downfold in the crystalline basement. To this downfold he attributes a fundamental significance in that it marks the source and site of the major Caledonian plutonic masses, and has, moreover, controlled

the development of the Caledonian regional metamorphism. To quote Goldschmidt's own words :—

" Versucht man, soweit das vorhandene Material es erlaubt, eine geologische Karte der Regionalmetamorphose im südlichen Norwegen zu zeichnen, indem man im autochthonen Kambrosilur Gebiete gleichartiger Metamorphose zusammenfasst, so erkennt man einen nahen Zusammenhang zwischen dem grossen Faltungsgraben und dem Auftreten der regional-metamorphen Gesteine. Die Gebiete gleicher Metamorphose verlaufen parallel dem Faltungsgraben, derart dass die stärkste Metamorphose im Graben selbst stattgefunden hat, die schwächste am weitesten vom Graben entfernt."

On such grounds the logical tectonic correlation must, therefore, be as between the Caledonian front in Norway and the southern margin of the Scottish Highlands. The South-West Highlands of Scotland, which constitute a well-marked thermal pitch depression, are then seen to represent a " syntaxis " within the mountain chain. Discussion of this and other aspects of the problem must, however, be deferred until some future occasion ; but, in conclusion, one must merely emphasize again that, in orogenic processes, thermal structure and negative gravity anomalies represent contrasted expressions of one fundamental relationship, and alike serve to indicate the existence, site, and symmetry of the tectogenic " root ".

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Petrology of a Wealden Sandstone at Clock House, Capel, Surrey

By P. ALLEN

THE topmost band of sandstone in the Weald Clay at Capel (6[1]) is now[2] exposed for 100 yards, and varies in thickness from 8 inches at the southern end of the face to 1 foot at the northern end. The stone is glauconitic and highly micaceous, and carries so much fresh biotite on certain bedding-planes that they are heavily darkened. Flakes of biotite and muscovite commonly reach 2 mm. in diameter, and occasionally 3 mm. No petrological facies like it is known in the older Hastings Beds outcropping to the south and south-east. The petrography of the sandstone therefore merits description, and some discussion of the problems which it raises.

The bed lies with marked discontinuity on dark shales, and has a flat base. It coarsens slowly upwards, via horizontal bedding, and ends in a rippled top. Both symmetrical and asymmetrical ripples occur, but their minutely false-bedded interiors invariably point to pre-existing asymmetrical (migratory) ancestors. Most of the crests run N.–S., and the foresets slope westwards. Above the ripples come minutely current-bedded and interbedded sandy silts and silty shales (6), forming a complete passage back to normal dark shale. The sandstone forms part of a sedimentary " cycle " resembling in miniature those which dominate the Weald Clay and Hastings Beds below.

Sampling was carried out randomly from the entire length of face at a depth of between 4 and 6 inches below the top surface of the sandstone. Five samples were secured in this way, lying at distances of 30, 110, 155, 210, and 300 feet from the south end. They will be referred to in the present note as A, B, C, D, and E respectively. At site C, vertical sampling at intervals of 3 inches was also carried out.

COMPOSITION

Mean Detrital Composition.—The arithmetic mean composition of the sandstone was estimated from the five random samples as given in Table 1.

The deposit differs widely from all known earlier horizons (4) of equivalent coarseness in :—

(i) The high proportions of biotite and tourmaline.

(ii) The high proportions of brown and zoned grains among the

[1] References on p. 240.
[2] October, 1947.

TABLE 1

LIGHT DETRITALS (S.G. < 2.9)

Species. *Variety.*		*Percentage.*
Quartz, Quartzite, Chert		99·13
Glauconite		0·87
Felspar (Microcline, Albite-Oligoclase)		< 0·1
Muscovite, Biotite, Chlorite, Clay		Not determined

HEAVY DETRITALS [1] (S.G. > 2.9)

Biotite, Muscovite	Not determined, ratio B/M ≏ 9 : 1	
Black Iron Ore + Leucoxene		51·47
B.I.O.	53·26	
Leucoxene	46·74	
Zircon		10.26
Colourless	63·08	
Brown	35·78	
Purple	0·16	
Yellow	0·98	
(Zoned)	(26·7)	
Rutile		1·83
Red + Brown	63·72	
Yellow	36·28	
Tourmaline		28·22
" Mixed "	90·62	
Green	3·57	
Blue.	2·58	
Parti-coloured	3·23	
(Acicular aggregates)	(6·01)	
Anatase		4·35
Yellow	98·3	
Colourless	1·7	
Garnet		0·401
Colourless	97·5	
Brown	2·5	
Apatite		0·599
Staurolite		0·217
Brookite		0·017
Unknown		2·65

zircons, and of parti-coloured and acicular aggregates (often penetrating quartz) among the tourmalines.

(iii) The low proportions of zircon and rutile.

No local facies, *of any coarseness*, is known in the Ashdown or Tunbridge Wells sands which even approaches this in composition. Optically and crystallographically the minerals remain very similar to their Hastings forerunners.

There can be little doubt that the Clock House sandstone represents

[1] If the precisions of these percentages are required, their standard errors may be derived from the data given in Table 2.

an early stage of the sweeping petrological changes that occurred near Dorking in late Weald Clay times (5).

Variation in Detrital Composition.—The variation in composition of the detrital heavy fraction along the 100 yards exposure was estimated as follows :—

TABLE 2

Mineral Species	Absolute Variation: Range (%)	Absolute Variation: Standard Deviation (%) ±	Theoretical Random Variation (%) ±	Relative Variation (k) $\left(= \frac{\text{St. Dev.}}{\text{T.R.Var.}}\right)$
B.I.O. + Leucox.	44·9 – 58·2	5·39	1·98	2·7
Zircon . .	4·9 – 15·1	3·84	1·20	3·2
Rutile . .	0·78 – 3·1	0·961	0·530	1·8
Tourmaline .	22·8 – 31·8	3·86	1·78	2·2
Anatase . .	2·3 – 6·2	1·70	0·807	2·1
Garnet . .	0·23 – 0·68	0·182	0·250	0·7
Apatite . .	0·30 – 0·93	0·282	0·305	0·9
Staurolite . .	0·0 – 0·46	0·173	0·184	0·9
Brookite . .	0·0 – 0·08	0·0380	0·0516	0·7

These values are of the same order of magnitude as those commonly observed in Hastings facies of equivalent coarseness (4).

Authigenic Composition.—The most abundant and interesting authigenic mineral was iron pyrites. Attaining its greatest frequencies near the middle of the exposure, this mineral exceeded, both in volume and in weight, the entire detrital heavy fraction of sample C. It occurred principally as clusters of about a dozen octahedra. No other crystal form was recognized.

In the surrounding silts and shales iron pyrites was dispersed even more widely. Most of the samples from these beds (Site C—e.g. sample 1, below) had to be treated with H_2O_2 before the detrital suite could be studied.

Certain of the anatases (included above in the detrital suite) were also authigenic. This conclusion was based on (*a*) the frequent presence of minute euhedra protruding from leucoxene aggregates, and (*b*) the high proportion of euhedra present in the species generally (Table 3).

PARTICLE SIZE

Mean Detrital Size and Sorting.—Samples A–E yielded zircon size indices (4) of 49·0μ, 48·6μ, 44·1μ, 43·5μ, and 53·2μ respectively. Their zircon sorting indices (= standard deviations of the size distributions (4)) were 11·8μ, 12·1μ, 11·5μ, 13·0μ, and 13·0μ. These values are very close to those obtained from Hastings facies of

similar coarseness (4). The size distributions were markedly symmetrical.

Particle Shape

The arithmetic mean proportions of euhedra within the various heavy detrital species were estimated as follows :—

Table 3

Species. *Variety.*	*Mean % Euhedra.*	
Black Iron Ore		0·36 ± 0·248*
Zircon		16·9 ± 3·89
Colourless	17·8 ± 4·72	
Brown	8·8 ± 3·14	
Purple	0·0	
Yellow	0·0	
(Zoned)	(24·4 ± 3·55)	
Rutile		2·7 ± 1·68*
Red + Brown	2·2 ± 1·41*	
Yellow	6·7 ± 6·66*	
Tourmaline		0·12 ± 0·116*
Anatase		14·2 ± 2.98
Yellow	14·2 ± 2·98	
Colourless	0·0	
Garnet		0·0
Apatite		0·0
Staurolite		0·0
Brookite		0·0

*Mean percentage therefore not significant.

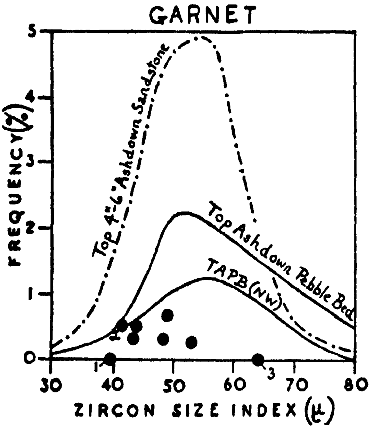
The figure for zircon is much higher than normally occurs in the Hastings Beds. Proportionately, it is wholly accounted for by the increased percentage of the zoned variety (see, e.g. (4)).

Covariation Between Composition and Particle Size

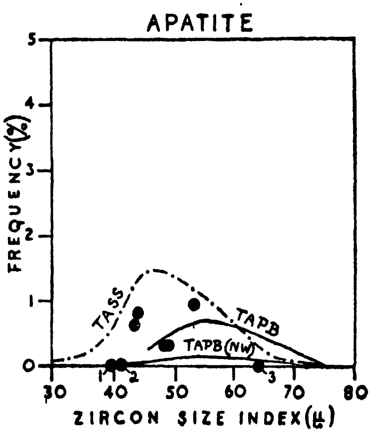
The abundance of certain heavy detritals in the earlier Hastings Beds is strongly related with detrital particle size (expressed as the zircon size index). This is particularly marked in the species garnet, apatite, staurolite, kyanite, and sillimanite (1, 2, 3, 4). Garnet and apatite tend to be most abundant in " heavy " facies of intermediate grade (approx. 40μ–60μ, z.s.i.) and to fall off rapidly towards the finest and coarsest facies. Staurolite, kyanite, and sillimanite, on the other hand, though also absent or rare in the finest facies, increase steadily in abundance towards the coarsest. The minerals within each of these groups are concluded to have travelled together in the same drainage-system, and the two groups themselves are thought to have travelled apart. Garnet and apatite came from the north-east, and staurolite, kyanite, and sillimanite mostly from the south-west (4). It is consequently important to discover the status of these minerals in

the Weald Clay. The present exposure has initiated a start on the problem.

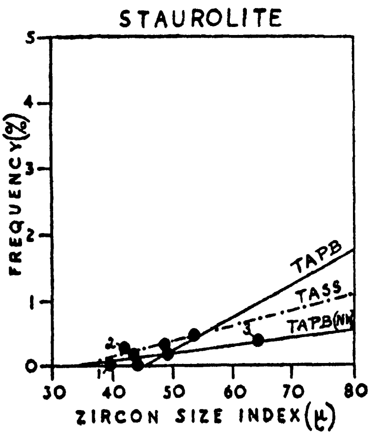
The frequency-grade points for the analyses A–E are plotted on the accompanying scatter-diagrams (Text-figs. 1–3). In order to extend the



TEXT-FIG. 1.



TEXT-FIG. 2.



TEXT-FIG. 3.

range of grade, three other analyses of Weald Clay made to date are included. Sample 1 came from sandy silts 1 inch above the Clock House sandstone ; sample 2 from a sandstone band outcropping at South Godstone (12½ miles north-east), and sample 3 from the same sandstone as the last, but 1 mile further east (Lane End, Crowhurst). The average (least-square) trends of corresponding correlations at

typical earlier (Hastings) horizons are indicated on the diagrams by regression curves representing the average change of frequency with grade. The new analyses conform to the same general principles, garnet and apatite being most abundant in facies of " intermediate " coarseness, and staurolite increasing steadily with grade.

Precise comparison with earlier horizons is, of course, impracticable at the present stage, but the possible existence of one major difference may be pointed out. Whereas the frequencies of staurolite and apatite lie close to typical Hastings regression lines, those of garnet lie at some distance, being significantly lower than would have been expected (for similar degrees of coarseness) at earlier horizons.

In the present state of knowledge there is no necessity to postulate sweeping changes of drainage, source, etc., to explain this, for the new frequencies of garnet are not very different from those which might have been expected in the underlying top Ashdown sediments at Clock House. Partition-analysis of the relationships in the Ashdown rocks further south-east has already shown that the frequencies of all three minerals decline north-westwards (4), though maintaining essentially similar types of relation with grade. This tendency has been attributed to the presence of a northerly and/or north-westerly inflow (contributing garnet-, apatite-, and staurolite-poor detritus), and is indicated on the present diagrams, in the case of one Ashdown horizon, by regression lines pertaining to the north-western half of the outcrop alone. Extrapolation north-westwards thus tends to lower the frequencies of garnet towards those observed at Clock House.

Conclusion

Since no fundamental change in the early Wealden system of three inflows need be postulated for the Ashdown Beds–Weald Clay interval, the remaining peculiarities of the Clock House sandstone may be attributed to the closer proximity of the north-western inflow. This conclusion appears to be confirmed by the Hastings Beds. At several horizons (see, e.g. (4)) biotite occurs only on the northern and north-western margins of the area of outcrop, tourmaline and zoned zircon are most abundant on the north-west margin, and zircon and rutile are least abundant on the north-west margin. The average local coarseness of the deposit is close to that at Clock House in each case.

Hayward's " Dartmoor " detritus seems to have come, as indeed it should have, via the *north-western* inflow.

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CORRESPONDENCE

THE CHARNIAN SYSTEM

SIR,—In Professor Watts's posthumous memoir on Charnwood Forest, reviewed in your last number (*ante*, p. 118), there is one observation needing some correction.

On p. 115 of the Memoir reference is made to the views of Professor Kendall on a " porphyroid of Peldar type . . . met with in a boring at the base of the Oxfordian at Bletchley ". Kendall, however, also wrote in the same Final Report of the Royal Commission on Coal Supplies (pt. ix, p. 25) : " I suspect that some beds of greater geological age than Oxford Clay occur in the lower part of the Bletchley bore-hole." The Calvert boring confirmed this suspicion and made a new interpretation of Bletchley possible, with Lias resting on the Charnian (Davies and Pringle, *Q.J.G.S.*, lxix, 332–3). As the Tremadoc Shales occur at Calvert in exactly the same position as the Charnian at Bletchley (only 12 miles away) it is highly probable that the latter are *in situ* and not boulders.

It is regrettable that the later interpretation of the Bletchley boring was overlooked in the Survey Memoir " On the thickness of Strata . . . " (1916), where the Oxford Clay is given as 410 feet thick instead of 192 feet.

A. MORLEY DAVIES.

AMERSHAM,
BUCKS.
25th May, 1948.

USE OF THE NATIONAL GRID

SIR,—The reference to the new ordnance maps in the May–June number of the *Geological Magazine* prompts me to venture to suggest to geologists engaged in field mapping in this country that the fullest possible use should be made of the national grid. Speedy and certain identification of exposures described in geological literature is important both to the research worker who may wish to re-examine the evidence on the ground, and to the student who is endeavouring to make himself acquainted with representative sections, and furthermore is a convenience to the geologist who, without being seriously concerned with details, nevertheless wishes to obtain a general idea of the structure or stratigraphy of an area which he may be visiting. Yet it is all too common to find that descriptions of localities are based on some feature that is not shown on the present one-inch map, and which is perhaps no longer in existence. An old quarry or barn may have been well known at the time the mapping was done, but after 20 or 30 years changes may have taken place that make it impossible to recognize the reference point ; a stream, lane, or farm may be named on the six-inch map but not on the one-inch, and it is not always practicable to consult the six-inch map, whilst local inquires may waste much time, with no certainty of success. Merely by the use of the one-inch gridded map a reference can be given to the nearest 80 yards, and the new 1 : 25,000 maps give greater precision with equal ease.

Related to this plea for the use of the national grid is another for adequate and accurate topographical detail in large-scale maps. I recently wished to use a two-inch geological map illustrating a paper ; topography was limited to the larger streams—there were no roads, villages, etc. It seemed that it might be convenient to add the national grid for ready comparison with both the one-inch and 1 : 25,000 maps. A photographic copy made on the 25,000 scale was compared with the ordnance map, but the streams were so generalized that an exact " local " fit was often not possible even on a tracing table, whilst the inaccuracies were sufficient to preclude a satisfactory " general " fit which would enable the grid to be made use of. Another map on the same scale had a few widely-spaced contours, but even then could not be accurately fitted either locally or generally to the ordnance map.

In a third instance a map which, being of an open character, had ample room for topographical detail, had, besides the geological lines, a few stream courses and village churches but no roads. It was accordingly difficult to locate boundaries. The map happened to be on one of the published scales of the ordnance survey, and I supposed that it would be easy to transfer the geology to the ordnance map by simply

tracing it through. I found that although there was usually a good local fit on the few streams shown, it was not possible to get a satisfactory general fit, and consequently in areas away from the streams there was some uncertainty about the positions of boundaries.

I have also noticed instances of maps which lack a graphic scale and are incorrectly stated to be so many inches to a mile ; this was the scale of the original which was reduced when the block was made, and there is no direct indication of the scale of the printed map, which has to be worked out by comparison with an ordnance map.

These have all come to my notice within the past few months, although the maps themselves range over many years. In every case much, if not all, of the difficulty of using them would have disappeared had there been a national grid in existence and had it been accurately incorporated in the original map.

P. EVANS.

THE BURMAH OIL CO., LTD.,
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5th June, 1948.

YOUNGER TECTONICS AND EROSION IN WESTERN AUSTRALIA

SIR,—In a recent discussion in this Magazine, which has only now come to hand,[1] C. A. Cotton postulates that the tempo of denudation in Western Australia during the Pliocene and Pleistocene could not possibly have been rapid enough to allow the levelling down of a strong relief newly created by folding and faulting of late Miocene or Pliocene age. He suggests that the tectonic movements in the North-West Basin to which I have ascribed such an age must have taken place rather earlier, though he does not say when. He finds support for these conclusions in certain features of the geology of Victoria and New South Wales.

Unfortunately, however, these theoretical deductions are contradicted by field evidence, and I also fail to see the relevance of geological observations in south-eastern Australia for the interpretation of the geological history of remote parts of Western Australia. Incidentally, the south-east corner of Australia is a good deal nearer to New Zealand than to the North-West Basin of Western Australia. Professor Cotton has opened a discussion on a most interesting subject and I regret more than ever that I found it impossible to deal more fully with the

[1] C. A. Cotton, Query as to the Tempo of Denudation in Australia. *Geol. Mag.*, lxxxv, 1948, 54–6.

physiography, structural history, or even palaeogeography of Western Australia in a publication which, as its title suggests, had stratigraphy as its main subject.[1]

After my second visit to the North-West Basin in 1939, I was much impressed by the amount of faulting and folding I had seen and found it hard to believe that all this could have happened at once. So I wrote [2] as follows: "... the present structures must be due to at least two, probably three, periods of crustal activity in this part of Western Australia." But then at that time we knew a lot less about the North-West Basin than we do now.

In dealing with tectonic movements in this area one has to distinguish between two problems; (1) the relationships between the Permian and the Mesozoic, and the Mesozoic and Tertiary rocks, and (2) the younger movements.

Little is known about the Permian-Mesozoic contact, which nearly everywhere is a faulted one. Raggatt [3] found evidence of broad warping of the Permian rocks before the deposition of the Cretaceous, with angular unconformities possibly amounting in places to about 10°. In other places no such unconformities exist. No further investigations into these tectonic relationships have as yet been made. Some years ago Jurassic was discovered in a small fault block,[4] but its relationships to younger and older beds are unknown. On the whole, Raggatt's picture of broad post-Permian undulations is no doubt correct. These movements determine the nature of the Permian-Mesozoic contact, but they have little influence on the present surface distribution of the rocks. The latter is entirely controlled by much younger folds and faults, all of which belong to one tectonic phase; in other words, we are concerned with *Bruchfaltung*. The western half of the basin is a down-faulted area of weakly folded Cretaceous and Tertiary rocks which are thrown into a number of broad anticlines and synclines. Where the anticlines are built of resistant rocks they form low ranges, as in the North-West Cape Range, which is 1,200 feet high. Elsewhere the soft cores may be eroded away or even the flanks completely levelled down, as on the east side of the Cardabia anticline. The Cretaceous-Permian boundary fault in the Minilya River area is normal and west-dipping with the Cretaceous greensands in places occupying a vertical position.

[1] C. Teichert, Stratigraphy of Western Australia. *Bull. Amer. Assoc. Petrol. Geol.*, xxxi, 1947, 1–70, and *Journ. Proc. Roy. Soc. N.S.W.*, lxxx, 1947, 81–142.

[2] C. Teichert, Recent Research Work in the Permian of Western Australia. *Aust. Journ. Sci.*, ii, 1939, 7.

[3] H. G. Raggatt, Geology of North-West Basin, Western Australia ... *Journ. Proc. Roy. Soc. N.S.W.*, lxx, 1936, 100–174.

[4] C. Teichert, Marine Jurassic in the North-West Basin of Western Australia. *Journ. Roy. Soc. West. Aust.*, xxvi, 1940, 17–25.

The Permian strata which occupy the eastern half of the basin are strongly dissected by antithetically east-dipping faults and have been folded locally in varying degrees of intensity. Individual fault blocks are commonly tilted 20–25°, but higher dips occur near the faults. Between the Cretaceous-Permian boundary fault and the first antithetic east-dipping fault to the east the beds are strongly folded into synclines. Strong faulting near the eastern margin of the basin has already been described by Raggatt in 1936. Faults with throws between 1,000 and 2,000 feet are quite numerous in this area.

That all this folding and faulting dates back to one, relatively young geological period, was already recognized by Raggatt who wrote[1] that " folding took place on a large scale in the late Miocene or Pliocene."

To say, as I did in 1947, that the area has since undergone " almost perfect planation " was a slight overstatement. The present features of the faulted terrain depend of course very much on the hardness of the rocks. I could lead Professor Cotton across 2,000-ft. faults of which not the slightest trace can be detected in the present physiography. In the Minilya River area, for example, the greensands and shales on both sides of the fault separating the Permian from the Cretaceous-Tertiary and also many fault blocks close to this fault, have been completely planed down. Where hard sandstones and limestones are affected fault scarps are formed which may rise 300 to 400 ft., in places even higher, above the general level of the plains. This is particularly so near the eastern margin of the basin.

The youngest rocks affected by these movements are Miocene, perhaps middle Miocene, although the possibility of the presence of somewhat younger beds cannot be ruled out.

In the coastal belt, between Carnarvon and North-West Cape, we seem to have a more or less conformable Cretaceous-Tertiary sequence which includes rocks of Eocene, Oligocene, and Miocene age. Miocene strata occur also 110 miles inland in the Kennedy Range [2], but their stratigraphical relationships are as yet unknown. Most probably these rocks are preserved here as erosion remnants in fault blocks at 1,000–1,200 feet above sea-level.

The earliest date for the folding and faulting of the Permian as well as younger rocks is the late Miocene ; more probably the movements took place during the Pliocene. To disregard field evidence would be a serious error indeed. If Professor Cotton sees " vast implications " I suggest that they should be faced. Obviously conditions in the North-West Basin of Western Australia during the Pliocene (possibly late

[1] *Op. cit.*, p. 169.

[2] C. Teichert. The genus *Aturia* in the Tertiary of Australia, *Journ. Paleont.*, xviii, 1944, 73–82.

Pliocene) and Pleistocene were such as to allow the removal by erosion of very considerable quantities of sediments and the levelling down of large tracts of country which only recently had undergone *Bruchfaltung* on a considerable scale, no doubt in connection with the elevation of the shield after the Miocene submergence. As observed on a recent field trip remnants of the gravels and conglomerates of this denudation period cover large areas in the Minilya River area. These deposits have been themselves subjected to more recent erosion and they are still being eroded at the present time.

Laterite is essentially restricted to the ancient shield and does not occur in the North-West Basin. Since the laterite seems to have formed on the newly-elevated shield as a subsoil (hardpan) under conditions resembling those of the wet tropics, there must have been a large amount of run-off from the plateau with consequent erosion and levelling of the marginal regions.

Cotton's statement that 100,000 cubic miles of rock would have to have been removed by erosion leaves one puzzled. From the figures given in my paper—area of North-West Basin 40,000 square miles thickness of sediments increasing from less than 5,000 feet in the south to perhaps as much as 14,000 feet in the north—it is easy to calculate that about 80,000 cubic miles would be a rather optimistic estimate for the entire original sedimentary filling of the basin. Of this perhaps two-thirds or even more must still be left.

The amount of young erosion in the North-West Basin is no greater, perhaps even smaller, than contemporaneous denudation in the East Kimberley district in the north of Western Australia as also mentioned in my 1947 paper. Here, in the White Mountains near the Ord River, young Tertiary lacustrine deposits, tilted and weakly folded are now perched at the top of a range of hills, about 1,000 feet above sea-level and 600 feet above the bed of the Ord River and the level to which much of the surrounding country has been planed down.

This remarkable occurrence has been known since 1885. Hardman, Wade, and others have remarked on it and a more detailed account, already quoted in my 1947 paper, is now available.[1]

We may conclude then that the younger geological history of Western Australia has followed a course somewhat different from that of the eastern half of the continent—which will not surprise anyone who is familiar with both regions.

C. TEICHERT.

UNIVERSITY OF MELBOURNE,
14th June, 1948.

[1] R. S. Matheson and C. Teichert, Geological Reconnaissance in the Eastern Portion of the Kimberly Division, Western Australia. *Rept. Dept. Mines West. Aust. for* 1945, Perth, 1948.

BATHONELLA AND VIVIPARUS

SIR,—Mr. Yen's paper is so suggestive and so nearly convincing that I would like to ask some elucidatory questions :—

(1) Why is he at pains to establish what was already well known, that *Bathonella* in Oxfordshire and the Indre is associated with marine gastropods ? A casual reader of his paper might think this an important point, but it proves nothing, for when *Bathonella* was thought to be a *Viviparus* it was only supposed that it was brought into the sea by a river in the same way as the mammals and land plants in the (purely marine) Stonesfield Slates.

(2) Why does he not mention that both in Oxfordshire and in the Indre *Bathonella* is associated with another genus of gastropods hitherto accepted as of freshwater origin and found at no other horizon, namely, *Valvata comes* Hudleston and *Valvata benoisti* Cossmann ?

(3) How does he dispose of *Valvata comes* and *V. benoisti*, and of the other Valvatas recorded in the marine formations on the Continent from the Kimeridgian upwards and supposed to have been brought in by rivers ? Are these now to be considered generically different from the abundant Valvatas of the Purbeck Beds, or are all the Jurassic Valvatas marine ?

(4) If *Bathonella* and the Bathonian Valvatas are marine genera, how does he explain their occurrence at one horizon only in each place in hundreds of feet of marine strata full of gastropods, most of which have a long range ? The old idea that some temporary trick of currents floated them out into the basin from the mouth of a river provided a satisfactory explanation.

(5) Will he tell us shortly the characters that he considers distinguish *Bathonella* from *Viviparus* ? It is not enough to be given a description of the shell and to be told that in combination its characters "produce an entirely different aspect" from *Viviparus*, for if this is true how was it that all palaeontologists and conchologists up till now have been deceived, including M. Cossmann and W. H. Hudleston, both of whom studied, described, and figured Bathonellas, and why do his own photographs still make *Bathonella* look so deceptively like *Viviparus* ?

I hope Mr. Yen will believe that I have an open mind on the subject ; but his interesting suggestion naturally raises such questions as these.

W. J. ARKELL.

TRINITY COLLEGE,
CAMBRIDGE.

15th June, 1948.

A NEW GEOLOGICAL DEPARTMENT

SIR,—A department of geology is being established at this University College, and the geological section of the library needs strengthening. One of the best ways of doing this would be the establishment of a "separate collection". Would authors and readers of this Magazine be prepared to help by sending separates of their own papers, and including any other separates for which they have no further use? Any such help would be gratefully received.

GEOFFREY BOND.

DEPARTMENT OF GEOLOGY,
UNIVERSITY COLLEGE, HULL.
24th June, 1948.

REVIEWS

TWO PROBLEMS OF MARINE GEOLOGY: ATOLLS AND CANYONS. By PH. H. KUENEN. 4 plates and 28 text-figures. Kon. Ned. Akad, Wet., Verh. (Tweede Sectie) Dl. XLIII, No. 3, pp. 1–69. 1947.

Here are two independent papers, combined only by a joint title, table of contents, and juxtaposition in the same journal. The two approaches are similar in giving a general classified review of the various evidence and arguments put forward to account for atolls and submarine canyons. Both problems involve the consideration of Pleistocene changes of sea level.

"The borings on Maratoea Atoll and the coral reef theory of glacially controlled subsidence" is the subtitle of the first paper. After a description of Maratoea (E. of Borneo), the hypotheses of atoll formation without relative movement of sea level are discussed and rejected. The arguments for and against the subsidence theory (Darwin) and the glacial control theory (Daly) are enumerated and discussed. Two well logs, detailed in an appendix, show coral limestone to a depth of 500 m. below the raised rim of the atoll of Maratoea. Seismic data from Bikini (1947) are supposed to show coral formation to a horizontal boundary 600 m. below sea level. These are just two more recent and more powerful arguments for subsidence. The case for glacial eustatic control is also convincing in accounting for the present form of atolls, particularly the constant depth of the lagoons and passes. Emphasis is placed on marine corrosion of reefs by a lowered glacial sea level. Both glacial control and subsidence are shown to be necessary, compatible, and complementary; the eustatic change superimposed and standardizing structures due to larger and longer differential movements of the crust. It is surprising, however,

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A Deep Borehole at Formby, Lancashire

By P. E. KENT

DISCOVERY of a shallow oilfield in Triassic rocks in a fenland area west of Formby, as described by Lees and Taitt (1946, pp. 307–11), led to an attempt to determine the nature of the local Carboniferous rocks, which were regarded as the most likely primary source of the oil found in the Trias.

The oilfield lies 8 miles west of the boundary fault of the Lancashire coalfield. The site for the deep test well, Formby No. 1, was chosen near the crest of the faulted dome in the Keuper rocks responsible for the position of the shallow field. At that time it was supposed that the thickness of Permo-Triassic rocks would probably be rather less than 3,000 feet, but there was nothing to indicate the character of the Carboniferous rocks beneath. The nearest outcrops of Lower Carboniferous to the north (Clitheroe) are in the gulf facies; those in the south (Flintshire) are of block type; the boundary between these different facies could have lain on either side of Formby.

In the event, the Permo-Triassic rocks proved to be far thicker than had been forecast, and they were found to rest upon early Millstone Grit notable both for its indurated character and for its unusual facies. Drilling stopped in Lower Carboniferous Shales of gulf facies at 7,680 feet, the test being the deepest bore-hole in Britain up to the present time.

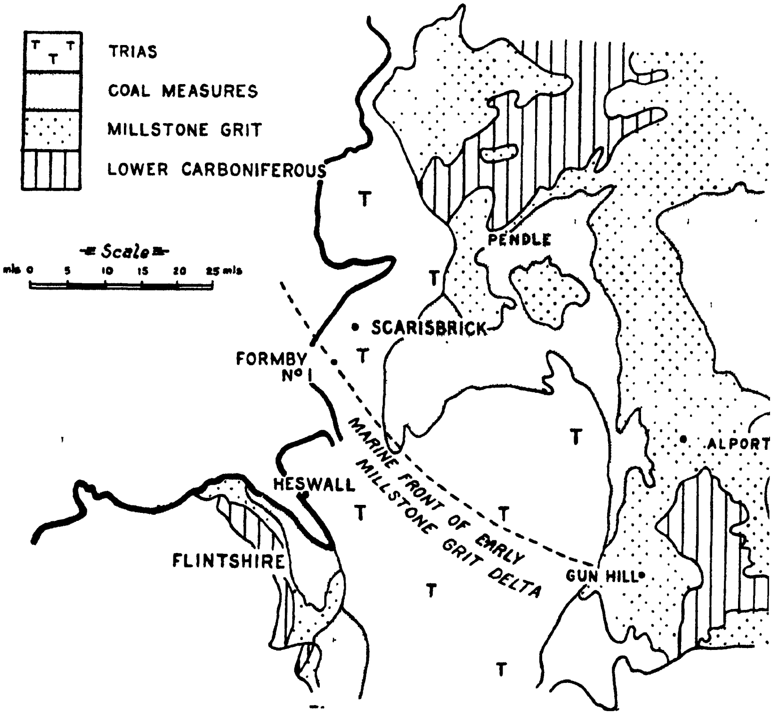
The account which follows is mainly assembled from the records of samples and cores compiled by Messrs. D. C. Ion, M. W. Strong, and M. P. Woodhead. We are grateful for much assistance received from members of the Geological Survey, especially from Drs. C. J. Stubblefield and F. W. Cope, and for helpful advice on correlation from Dr. R. G. S. Hudson, Professors P. G. H. Boswell, W. G. Fearnsides, and O. T. Jones. Finally, acknowledgment is made to the Chairman and Directors of the Anglo-Iranian Oil Company, Ltd., for permission to publish the results of the operations.

BORE-HOLE DATA

The well was sited approximately 1½ miles E.N.E. of Formby church (3° 1′ 44.2″ W., 53° 33′ 51.5″ N.) and was drilled during the

years 1940–47. The rotary table elevation (datum for measurements) was 19.3 O.D., approximately 9 feet above ground level.

		Thickness.	Depth of Base.
Superficial Deposits		91	100
Keuper	Waterstones	160	260
	Basement Beds	970	1,230
Bunter	Upper Mottled Sandstone	665	1,895
	Pebble Beds	1,235	3,130
	Lower Mottled Sandstone	120	3,250
Permian	Manchester Marls	290	3,540
	Collyhurst Sandstone	2,345	5,885
Upper Carboniferous, Millstone Grit		1,255	7,140
Lower Carboniferous penetrated to		540	7,680



TEXT-FIG. 1.—Sketch Map showing position of the Formby No. 1 boring in relatio[n to] other borings mentioned in the text.

THE STRATIGRAPHICAL SUCCESSION

As is usual in drilling by the mud-rotary system, coring was only carried out intermittently, the greater part of the succession being reconstructed from cuttings screened from the mud flush. In the

present bore-hole the first cores were taken at 2,570 feet, but the description is supplemented for the uppermost part from cores taken in shallow borings within a radius of 200 feet of the deep test.

1. *Superficial Deposits*, 91 feet

	Thickness.	*Depth.*
Downholland Silts (Scrobicularia Clay) . .	46	55
Shirdley Hill Sand	10	65
Boulder Clay	35	100

The Shirdley Hill Sand has been proved in the shallow wells nearby to be in winding channels cut in the Boulder Clay. Both Sand and Boulder Clay are levelled off at about 40–45 feet below surface (say 35 feet below sea-level) over the area of the oilfield.

The boulders included in the Boulder Clay are predominantly dark basaltic rocks. Quartzites are common, granitic rocks occur, and rare haematite, Carboniferous Limestone, and Chalk flint (one specimen) were found in the shallow bore-holes.

2. *Keuper*, 1,130 feet

On the crest of the faulted anticline which localizes the oil accumulation the Keuper Marl has been removed by erosion, so that Drift rests directly on Keuper Waterstones. The deep well was sited almost exactly over the concealed Keuper Marl featheredge, so that the full thickness of Waterstones is present.

	Thickness.	*Depth.*
Keuper Waterstones, 160 feet.		
Greenish grey shales, partly silty and micaceous with common carbonized plant fragments in the lower part, interbedded with fine grained well bedded sandstones	160	260
Keuper Sandstones (Basement Beds), 970 feet.		
Medium or fine grained sandstone, light grey except when oil stained, with occasional greenish shale partings	245	505
Buff and light grey fine or medium grained sandstone, often friable, with numerous small rounded grains	725	1,230

Identification of the Keuper Waterstones is based on lithology. The alternation of shales and fine cemented sandstone bands is characteristic of the subdivision elsewhere, and the development of suncracks, salt pseudomorphs, ripple marks, and "curly bedding" (seen in cores from adjacent shallow wells) provide further points of similarity. The uniform greenish grey colour is, however, unusual; it may reflect reducing conditions associated with vegetation (plant fragments being common in the lower part) or possibly reducing

conditions arising from the oil accumulation. That the latter may be important is suggested by rapid horizontal variability in colour of the Keuper Marl on the flanks of the field, and it may explain the absence of records of green beds in the old " Moreton Bore " half a mile south-east of the oilfield.

The Waterstones shales rest on the Basement Sandstones with a very sharp, clear cut junction. The lack of transition and the great change from massive current-bedded sandstones to argillaceous rocks suggests an appreciable non-sequence, during which major climatic and/or physiographical changes intervened.

3. *Bunter*, 2,020 feet

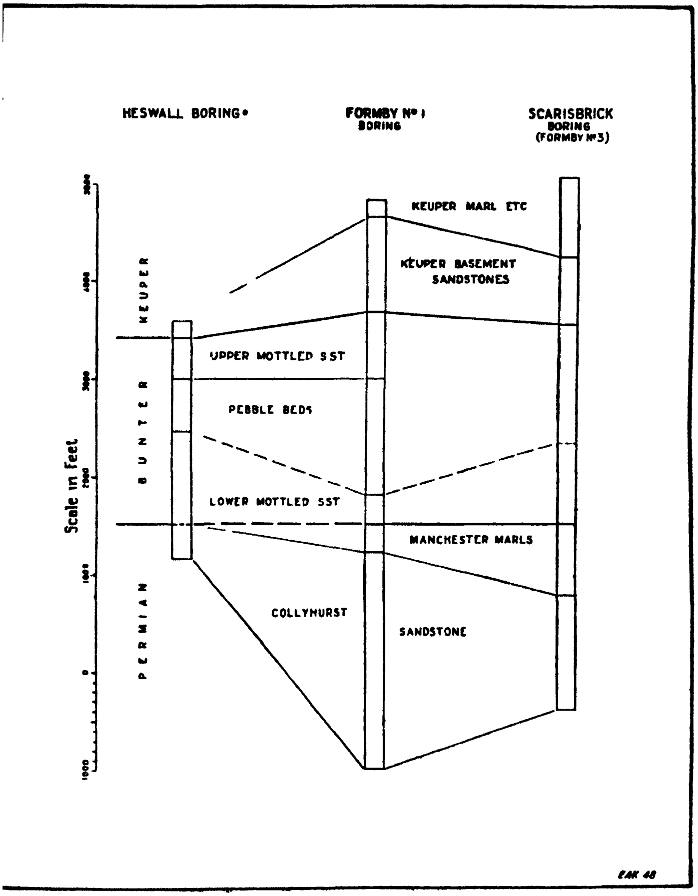
The top of the Bunter was taken at a sharp change from grey to red beds, and by a marked increase (going downwards) in the proportion of marl.

	Thickness.	*Depth.*
Upper Mottled Sandstone, 665 feet.		
Red marly sandstone, with variable amounts of deep red marl especially in the middle part, occasionally mottled with green . . .	665	1,895
Pebble Beds, 1,235 feet.		
Light brown fine sandstone with scattered pebbles of igneous rock ; conglomeratic beds at 1947–8, 2,310–36 ; occasional marl partings, selenitic near the base	705	2,600
Softer brown sandstone with sporadic quartz pebbles predominating over igneous rocks ; varying amounts of reddish and white clay, marl and greenish sandstone, becoming harder towards the base	530	3,130
Lower Mottled Sandstone ?, 120 feet.		
Bright red brown marly sandstone, finely micaceous, with bands of millet-seed grains, buff sandstone and a little gypsum . . .	120	3,250

Subdivision of the Bunter is a matter of some difficulty, and the classification adopted above shows the Pebble Beds considerably thicker and the Lower Mottled Sandstone thinner than in other places. The top of the Pebble Beds is defined in the bore-hole by the presence of pebbles, otherwise there is no important difference from the beds above. The predominance of igneous pebbles over quartzites in the upper 700 feet does not appear to have attracted attention in other places.

The Lower Mottled Sandstone is distinguished by the presence of millet-seed sands, by a change to a brighter colour, and by an increase in the amount of marl. The presence of gypsum suggests an approach to Permian conditions of deposition, and the Geological Survey

therefore prefer the alternative interpretation that these beds, in fact, belong to the Manchester Marl. The reading given above is adopted because the absence of limestones and presence of millet-seed sands is unlike typical Manchester Marl, and because a deep basin development is more likely to show an abnormal gypsum development than the absence of a subdivision.



TEXT-FIG. 2—Comparison of the thicknesses in the Permo-Trias of the Formby Area. *Classification from G. S. Well Catalogue, 1943.

4. *Permian*, 2,418 feet

The Lower Mottled Sandstone as defined above rests on a normal Manchester Marl development. As marl forms an important part of

both Lower Mottled and Collyhurst sandstones, while the Manchester Marl includes sandstone beds, determination of boundaries is far from easy. The preliminary account previously published classed only 107 feet of beds as Manchester Marl (Lees and Taitt, loc. cit., p. 310), but this relegated marls with a limestone band to the Collyhurst Sandstone and does not seem in line with the classification of other sections in the region. The writer prefers to adopt D. C. Ion's original grouping, the top of the marls being placed above the first marl without millet-seed grains, 10 feet above the highest limestone, and their base at the top of the first thick sandstone below the lowest limestone. This gives a thickness of 290 feet. One might alternatively include beds down to the lowest thick shale (3,670 feet) which would give a thickness of 420 feet ; this is perhaps more in line with the thickness of Collyhurst Sandstone below.

	Thickness.	*Depth.*
Manchester Marls, 290 feet.		
Red marl with anhydrite and thin beds of impure limestone, interbedded with reddish fine marly sandstone	70	3,320
Light red calcareous sandstone and marl	30	3,350
Dark brown silty shale and marl, with increasing proportions of grey fine sandstone towards the base	115	3,465
Red shale with thin beds of dolomite, subordinate to interbedded grey and fawn sandstone	75	3,540
Collyhurst Sandstone, 2,345 feet.		
Light coloured fine to coarse sandstone with red shale streaks ; shale and marl predominant in lower 40 feet	130	3,670
Grey, fawn, and white sandstones, friable or hard, with red shale partings	504	4,174
Grey to white hard sandstone alternating with beds of soft millet-seed sand ; millet-seed becoming predominant in middle and lower part	1,456	5,630
Fine reddish brown soft millet seed sand with hard red calcareous sandstone bands and a thin pebble bed at the base	255	5,885

According to the " Manchester Memoir " the Collyhurst Sandstone is " everywhere a soft red sandstone ", and the few outcrops nearer Formby agree with this. The colour in the deep test is thus unusual, but it was a feature also of the Scarisbr ck (Formby No. 3) deep bore-hole. It may be that the redness is characteristic of the margins of the deep basin only.

The measurement of 2,345 feet for the Collyhurst Sandstone is far greater than other records, and the Formby No. 1 sequence is the thickest Permian of any facies known in the country.

Mr. I. S. Double examined the heavy minerals in specimens of the lower Collyhurst Sandstone. The samples (well cuttings) from intervals between 4,850 and 5,510 yielded abundant zircon and calcite, frequent tourmaline, variable amounts of pyrite, rare anatase, apatite, and muscovite ; magnetite and probably ilmenite were present in quantity. This is a typical assemblage for a Permo-Triassic rock of the district. A similar suite was obtained from red shale cuttings within the Carboniferous, but subsequent analysis of cores has shown the true Carboniferous assemblage to be distinctive, and the red shale was probably cavings.

The pebbles at the base of the Collyhurst Sandstone were found by Dr. Phemister to include cherts, gritty micaceous mudstone with carbonate rhombs, and silicified rock containing microspherulitic quartz. Some of the pebbles were similar to the underlying Carboniferous rocks ; these were subangular, while other types were more rounded.

5. *Upper Carboniferous*, 1,255 feet

The Permian millet-seed sandstones, with a few pebbles at the base, proved to rest on an exceedingly hard, silty siliceous and haematitic rock, in superficial appearance very similar to the widespread " liver-coloured quartzites " of the Midlands Bunter Pebble Beds. In this rock conventional drilling tools made very slow or at times no progress, and after a number of experiments operations were suspended, to be resumed again after the war.

The specimens of hard beds close to the Permian were examined by a number of people, and their age remained in doubt until Dr. Phemister found a vegetable fragment, suggestive of Carboniferous date. Professor O. T. Jones found evidence that the rock, now mainly siliceous, was in part originally dolomitic, with sandy and muddy material, some of which was probably wind borne. Heavy minerals from a core of these upper beds were determined by Miss P. S. Walder as brookite, zircon (clear and dusty), tourmaline (brown, blue, and green), rutile (red and yellow), kyanite, sillimanite, ilmenite, leucoxene, glauconite, and muscovite, a much more varied assemblage than in the overlying Permian. Lower down, M. W. Strong identified a series of more or less silicified dolomitic limestone bands, and obtained a microfauna which has been identified by A. G. Davis. The lithological facies and occurrence of abundant sponge spicules led Strong to suggest a correlation of these beds with the Cefn-i-Fedw sandstone of N. Wales. The macro-fossils determined by Dr. Stubblefield in the lower part and in the beds beneath finally established the age of the series as early Millstone Grit.

	Thickness.	Depth.
Dolomitic Beds, 305 feet.		
Banded red sandy and muddy silica rock ; mainly of small angular quartz grains in a matrix of cherty material with nests of recrystallized dolomite ; varying to a sandy dolomite with incipient silification. Scattered rounded sand grains and sponge spicules occur . . .	24	5,909
Reddish calcareous sandstone, with angular quartz grains	46	5,955
Red and brown siliceous silts with silicified and unaltered dolomitic limestones. *Endothyra* cf. *ornata*, *Agathammina* cf. *pusilla*, *Tetrataxis* cf. *decurrens*, ? *Nodosarina* sp. and ? *Archaeocidaris* spine in lowest 15 feet . . .	90	6,045
Pink silicified calcareous shale	52	6,097
Red siliceous silt with sandy dolomitic limestone as above, and calcareous sandstone with sponge spicules	93	6,190
Cherty Beds, 192 feet.		
Silicified silt, shale and sandstone, with pale, yellowish and pink chert beds containing sponge spicules throughout. In part represents a silicified carbonate (? dolomite) mud . .	192	6,382
Sandstone with Limestones, 334 feet.		
Pinkish fine grained haematitic silica-cemented mudstone and sandstone, calcareous below, with reddish tough silty shale bands and calcite veins. Sponge spicules at 6,460. Core with fragmentary brachiopods at 6,496 including Orthotetids, Athyrid, Rhynchonellids, and Productid	118	6,500
Pink and white sandy limestone and purple siliceous siltstone with cherts, and red calcareous sandstone, with sponge spicules .	63	6,563
Red and purple calcareous or silica cemented sandstone with hard purple shale and siltstone bands ; some clear chert enclosing haematite grains. Shale partings increasing towards base .	153	6,716
Silty Shale Beds, 154 feet.		
Reddish purple silty shale with interbedded thin red calcareous sandstone beds in the middle and lower parts	112	6,828
Impure grey and reddish calcareous silts, with thin impure limestones	42	6,870
Calcareous Sandstones, 270 feet.		
Pink or grey very fine grained mainly calcareous sandstone with spicules in the upper part, and a shelly bed at 6,877	30	6,900
Pink and red very fine grained calcareous sandstone with thin beds of brownish limestone containing crinoid debris	7	6,907
Pink calcareous very fine grained sandstone interbedded with purple siltstone, with thin limestone streaks near the base ; calcite and barytes veining (*Base of reddened beds*) . . .	93	7,000

	Thickness.	Depth.
Grey sandy limestone and medium grained hard calcareous sandstone, containing limestone pebbles, with *Dielasma* sp., Orthotetids, *Productus* (*Echinoconchus*) cf. *punctatus*, *Naticopsis*? sp. Fenestellids, spicules and *Paraparchytes* cf. *okeni* (Munst.)	13	7,013
Banded grey very calcareous siltstone, passing locally into limestone, and calcareous pyritic micaceous sandstone, partly spicular	38	7,051
Very fine grained calcareous sandstone, with occasional shelly streaks	29	7,080
Siltstone and sandstone, grey streaked with red, with spicular layers	60	7,140

The first point of interest is the depth of reddening and induration beneath the Permian. The Millstone Grit beds were almost uniformly red or purple for 1,115 feet to a depth of 7,000 feet; at this level there was a sharp change to grey, and the formation became notably softer so that cores could be taken without too much difficulty. This thickness of reddened beds is equalled by only one previous record of sub-Permo-Trias weathering in this country; a case of deep weathering of Lower Carboniferous rocks in the Carlisle basin (Trotter, 1939). The silicification of dolomitic material found in the uppermost 500 feet of the red beds may be related to the availability of easily soluble opaline silica in the form of sponge spicules, which are a notable feature of the succession.

The second peculiarity refers to the facies of the beds. The Millstone Grit of Northern England is usually regarded as a deltaic formation, mainly fresh water with intercalations of marine goniatite and *Lingula* bearing shale. Here above the Bowland Shales are three groups of more or less calcareous sandy beds with marine shelly faunas, a group of calcareous silty beds, and a group of cherts with sponge spicules. At least half and possibly all of this succession is marine.

Shelly faunas in the earlier Millstone Grit are well known in the Yorkshire Dales (Tonks (1925) records three in the Nidderdale succession), but the intervening beds are of the usual non-marine type. At the nearest outcrops to Formby, around Pendle Hill, shelly intercalations have not been found in the equivalent beds. We are therefore led to think of Formby as being situated on the seaward margin of the early Millstone Grit delta, where accumulation took place entirely under marine conditions. The succession may, as Dr. Hudson has pointed out, be regarded as the foreset beds of the delta, the topset beds being represented by the mainly freshwater accumulations of north Lancashire.

With such an unusual facies the correlation of the succession presents an interesting problem. The beds penetrated are entirely distinct from the Upper Millstone Grit of Rossendale and Upholland (11 miles east

of the Formby bore), and as in addition shelly intercalations are confined to the E and H zones elsewhere it seems reasonable to regard the succession as wholly pre-R zone. It is also significant that only one major cycle of deposition is represented, so that the series above the Bowland Shales can be equated with the Pendle Grit Group of the outcrop, with a fair degree of probability that the Sabden Shales and later Grits are unrepresented. On this reasoning the beds are provisionally ascribed to the E zone.

Dr. Hudson has commented on the tendency towards a shelly marine facies in North Staffordshire as well as at Formby, and he has suggested the following tentative correlation with the succession proved in the Gun Hill Boring (Hudson and Cotton, 1945, p. 277) :—

Formby.	*N. Staffordshire.*
Dolomitic Beds	Thorncliffe Sandstone (with limestones)
Cherty Beds Sandstones with Limestones	Crowstones
Silty Shale Beds	Shale with Siltstones
Calcareous Sandstone	Onecote Sandstone

On this correlation the series would be mainly of E.1 date. Towards the south-west the Cherty Beds are probably represented by the Holywell Cherts, and the series as a whole probably finds its reduced equivalent in the Cefn-i-Fedw sandstone.

6. *Lower Carboniferous*, 540 feet

The Upper/Lower Carboniferous boundary is not marked by a fundamental change ; the series still shows an alternation of shales, silts, and sands, but at 7,140 feet silts and shales become predominant. *Posidonia membranacea*, as the zone fossil of P_2, is taken as marking Lower Carboniferous beds (although varieties range up into E), and Dr. Hudson suggests that *Girtyoceras costatum* may also be taken as indicating uppermost Visean, as at Alport. The horizon of the main lithological change above this level is consequently adopted as the top of the Lower Carboniferous.

	Thickness.	*Depth.*
Bowland Shales, 320 feet.		
Interbedded dark grey siltstone and sandstone, with thin black shale partings. *Pinnularia capillacea* (Lind. and Hut.) ? *Girtyoceras* at 7,155	54	7,194
Black calcareous shaly mudstone and dark grey siltstone interbedded with sandstone streaks throughout. *Posidonia membranacea* McCoy, cf. *Girtyoceras costatum* (Rup.), nautiloid, *Hindeodella* sp., *Ozarkodina* ?	52	7,246
Grey and white fine grained or silty calcareous micaceous sandstone, carbonaceous below with occasional black shaly partings . .	59	7,303

	Thickness.	Depth.
Black calcareous pyritic shale and shaly mudstone with sponge spicules and streaks of sandstone increasing downwards ; calcite veined. *Posidonia* cf. *corrugata* R. Eth, cf. *Sudeticeras* sp., ? *Girtyoceras*, *Coleolus* cf. *namurensis* (Dem.)	27	7,330
Grey very calcareous siltstone with a bed of sandy limestone containing sponge spicules, *Posidonia* sp., *Dimorphoceras* sp., cf. *Sudeticeras stolbergi* (Patt.) at 7336–8. Orthotetid and Productid fragments in a thin limestone at 7,338 feet .	21	7,351
Interbedded black shale and grey silty shale, with streaks of fine sandstone	109	7,460
Bedded Limestones, 90 feet.		
Medium grey sandy and silty limestone, crinoidal in the upper part, in thin beds with dark shale partings, calcite veining	50	7,510
Grey silty limestone and calcareous siltstone, thinly bedded as before. Calcite and barytes veining	40	7,550
Shales with Limestone, 130 feet.		
Dark shale and sandy siltstone stone, with occasional thin crinoidal limestone streaks .	55	7,605
Black calcareous shale with sandy and silty bands, with four thin limestone beds in the lower part	75	7,680

Superficially this succession is similar to that of Pendle, with its shale sequence parted by a sandstone (compare Bowland Shales with Pendleside Sandstone) crinoidal limestones overlying a bedded cementstone group (compare Ravensholme and Pendleside Limestones) overlying shales with limestone. Messrs. Stubblefield and Bisat date the 7303–30 fauna as P_2, so that unless the P_1 zone is very thin the beds of Formby are likely to be somewhat younger than their lithological equivalents farther north. The Bedded Limestones would in this case become, as Dr. Stubblefield has pointed out, approximately equivalent to part of the P_2 Cherty Limestones (1172–96) of the Alport Boring (Hudson and Cotton, p. 277). In the absence of more direct palaeontological evidence thinning may perhaps be regarded as more probable than diachronism affecting a series of such varied lithology, and the boring regarded as having passed through the Pendleside Limestone (7460–7550) into the Worston Shales beneath.

The Variscan Movement at Formby

A remarkable feature of the Formby succession is the extent of the pre-Permian uplift and erosion. Unless thickness trends in the surrounding area changed sharply in approaching Formby, it seems that 2,000 feet or more of Coal Measures and about 5,000 feet of Millstone Grit were removed before Permian sedimentation began. In addition to this, the reddening of 1,100 feet of the remaining

Millstone Grit implies elevation by at least this amount above sea level. The Formby area therefore appears to have been raised some 8,000 feet vertically with relation to the Manchester area and about 7,000 feet of sediments removed, before subsidence again supervened.

The deep weathering of the remaining Carboniferous is a warning against imagining this erosion as producing a deep valley cut far below the general level and subsequently filled with Permian sands, for it implies that Formby stood higher, rather than lower, than the less deeply affected rocks of the present Permian outcrops.

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Resemblances between Moine and " Sub-Moine " Metamorphic Sediments in the Western Highlands of Scotland [1]

By A. G. MACGREGOR

(PLATE XVII)

INTRODUCTION

IN 1939, Dr. Richey and Professor Kennedy gave a preliminary account of the geology of the Morar Anticline in Western Inverness-shire. In the core of this anticline they had found, structurally and stratigraphically below the Lower Psammitic Group of the Moine Series and in association with hornblendic orthogneisses, a complex of psammitic and pelitic rocks differing somewhat in character from the Moine metamorphic sediments (Text-fig. 1) ; to this mixed group of metamorphic rocks, which they consider to be separated from the Moine metamorphic sediments by a line of discordance, the name Sub-Moine Series was given (Richey and Kennedy, 1939). On the recently published Sheet I of the Geological Map of Great Britain, on the scale of 1/625,000, the Sub-Moine rocks have, however, been classed as Lewisian.

The years of war prevented Dr. Richey and Professor Kennedy from completing the preparations for the publication of the Morar map (One-Inch Sheet 61) and from progressing with detailed petrological work necessary for the writing of the memoir. On their retirement from the Geological Survey at the end of the war, the writer was assigned the task of preparing for publication the maps and memoirs on One-Inch Sheet 61 and on One-Inch Sheet 52 to the south.

Before the war, the position of the Moine/Sub-Moine boundary shown on Plate III of Dr. Richey's and Professor Kennedy's paper at the head of Loch nan Uamh had been moved farther south by Mr. V. A. Eyles [2] ; and this new line had been adopted by Dr. Richey. While studying the rocks of this key area, where all the groups of the Moine Series, and underlying rocks assigned to a psammitic group of the Sub-Moine, are exposed on hillsides, in new road-sections, in railway cuttings, and on the seashore, the writer found that he could

[1] Communicated with the permission of the Director of the Geological Survey and Museum.

[2] Mr. Eyles asks me to state that, in finishing off the mapping in the Loch nan Uamh area, and especially near Loch Mama, he appreciated that, taken as a whole, the two groups had certain distinctive lithological characteristics, but found the change from one group to the other to be transitional. In consequence, he had great difficulty in deciding where to place the boundary, and did not consider that the line he drew represented an abrupt junction between two rocks of contrasted lithology and widely different age. Two subsequent visits to the area have confirmed his opinions.

detect no mappable line to define the base of the Moine Series. Mr. Eyles, after accompanying the writer to see in the field the new evidence on which this conclusion was based, has expressed his agreement.

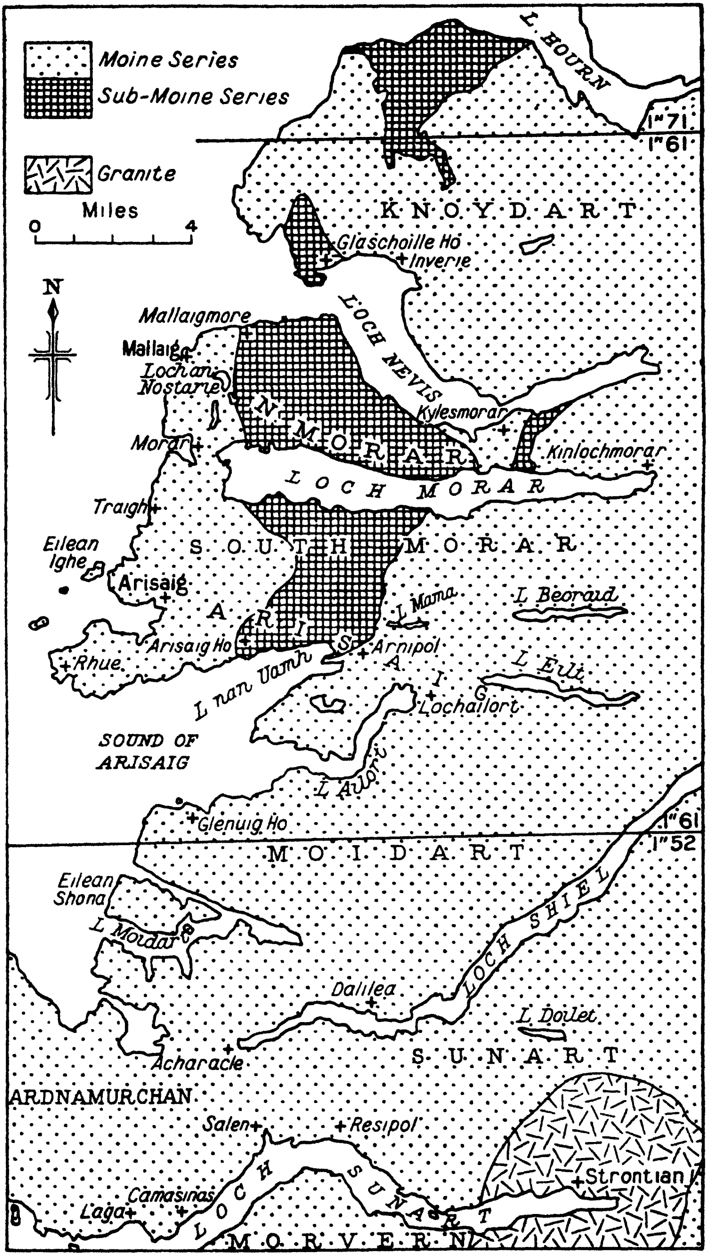
The new field evidence, strengthened by microscopic work on old and new rock slices from a wide area, throws doubt on some of Dr. Richey's and Professor Kennedy's somewhat tentative conclusions of 1939, and thus has a direct bearing on future work in this part of the Western Highlands. Research is actively in progress in the Glenelg–Loch Hourn area, where Dr. Richey and Professor Kennedy have suggested that there are rocks equivalent to the Moine and Sub-Moine Series of Morar (Text-fig. 1 ; see also 1939, p. 27, and 1/625,000 Geological Map of Great Britain, Sheet I). Because official publication of the new evidence in the "Summary of Progress" has been unexpectedly delayed since the end of 1946, the writer has been urged to put the facts and inferences on record elsewhere.

Calc-Silicate Ribs

In the Morar succession of the Moine Series of western Inverness-shire, pale quartzo-feldspathic calc-silicate ribs, containing garnet and zoisite along with hornblende or biotite and sphene, are present in parts of the Upper Psammitic and Striped and Pelitic Groups ; but they have not been found in the lower part of the latter group (the Lower Striped Schists) or in the underlying Lower Psammitic Group (1939, p. 28).

At the south end of the Morar Anticline, and elsewhere, the Moine Lower Psammitic Group, according to Dr. Richey and Professor Kennedy, rests discordantly on Sub-Moine psammitic rocks which they believe to be much older and in a different metamorphic state (1939, pp. 43, 44). During the writer's investigation of this region (east and north-east of Loch nan Uamh, which forms the eastern extension of the Sound of Arisaig) calc-silicate ribs of a somewhat different type were found : dominantly white or pink quartzo-feldspathic rocks, with local greenish streaks ; they are without garnet or zoisite, but are sphene-bearing and rich in epidote, and contain in several instances some very pale green porphyroblastic hornblende (Plate XVII, fig. 3) and (locally) calcite. The feldspar, as in the garnet-zoisite ribs, appears to be mainly plagioclase approximating to oligoclase in composition, but accurate determinations have not yet been made. These lenticular epidotic calc-silicate ribs (Plate XVII, figs. 1 and 2), from ½ to 2½ inches in maximum thickness, occur in the Lower Striped Schists (36371–3, 36803)[1] and in the Lower

[1] These numbers refer to rock slices in the Scottish collection of the Geological Survey.



TEXT-FIG. 1.—The Moine and Sub-Moine Series between Loch Hourn and Loch Sunart (according to J. E. Richey and W. Q. Kennedy).

Psammitic Group (36367) of the Moine Series and immediately below in an underlying belt of psammitic rocks previously assigned to the Sub-Moine Series (36363–6, 36380–3, 36782–3); they are particularly numerous and well exposed in cuttings on the Arisaig–Lochailort road in the vicinity of Arnipol cottage; for brevity of reference the term "calc-silicate ribs of Arnipol type" is suggested. Calc-silicate ribs (some of which were originally noticed by Dr. J. B. Simpson) in psammitic rocks of undisputed Moine age at Camastorsa (near Camasinas) and Laga, on the shore of Loch Sunart 15 miles to the south-south-west, have, on microscopic examination (36855–8, 36863), proved to be of this distinctive Arnipol type, i.e. non-garnetiferous and epidotic, and locally containing pale green porphyroblastic hornblende (36857 : Plate XVII, fig. 4).[1]

The facts recorded above provide part of the new evidence suggesting that all the psammitic rocks at the head of Loch nan Uamh (including those previously referred to the Sub-Moine) should be assigned to the Moine Series. False-bedding is another factor bearing on the relationship between these Moine and Sub-Moine rocks (*see also* pp. 271, 274). In the Loch nan Uamh–Lochailort area false-bedding is locally preserved in the Upper Psammitic Group of the Moine and also in rocks previously assigned to the outermost psammitic zone[2] of the Sub-Moine (1939, p. 43). In the latter, and throughout the whole of

[1] It may be mentioned for completeness (1) that sporadic bladelets of biotite may occur locally in all the ribs; (2) that some yellow pleochroic epidote has been found in ribs from Moine (36372, 36863, 36377) and from alleged Sub-Moine rocks; (3) that in one Arnipol rib (36373, 36803), in which pale hornblende is abundant, no epidote has been seen (Plate XVII, fig. 3); (4) that a minute garnet is present in one of the Camastorsa ribs (36856); (5) that in some ribs (e.g. 36857) the epidote mineral may approach, or possibly cross, the epidote/clinozoisite boundary; (6) that Mr. T. R. M. Lawrie has found a garnet-epidote calc-silicate rib of a pink colour (36377) in the Upper Psammitic Group of the Moine between Loch nan Uamh and Lochailort, and (7) that Dr. Richey and Professor Kennedy have recorded garnet-epidote-magnetite bands in Sub-Moine psammitic rocks (1939, p. 38).

[2] In the present paper the writer uses the term "outermost psammitic zone of the Sub-Moine" to designate outcrops of Sub-Moine psammitic rocks that are shown on Plate III of Dr. Richey's and Professor Kennedy's paper adjacent to outcrops of the Moine Lower Psammitic Group. On the west side of the Morar Anticline these authors assign such rocks to the Outer Psammitic Group of the Sub-Moine, but in the Loch nan Uamh area they describe them as "presumably Intermediate Psammitic Group" of the Sub-Moine; between Loch Morar and Loch Nevis they class them, on their Plate III, as "? Sub-Moine Outer Psammitic Group". This nomenclature is used because of a "somewhat tentative" hypothesis of recumbent folding in the Sub-Moine core of the Morar Anticline; the authors suggest that in this core the Outer Psammitic Group is the oldest, that the Intermediate Psammitic Group is younger, and that the Central Psammitic Group is the youngest (1939, pp. 42, 43, fig. 6, and Plate III). In the present paper the writer does not propose to discuss the evidence available for and against recumbent folding in the Sub-Moine.

the Moine Series, younger beds come on towards the south-east (cf. 1948, p. 20).

The rocks so far mentioned lie outside (to the west of) a broad belt of pegmatitic injection trending roughly north and south (1948, pp. 30, 31, and fig. 17). Non-garnetiferous epidotic calc-silicate ribs occur within the injection zone; for instance, in psammitic rocks of undetermined (probably Moine) age at Kinlochmorar, at the east end of Loch Morar (36797–8 : found by Mr. V. A. Eyles : see 1940, p. 72); and in psammitic rocks undoubtedly belonging to the Moine Series, near Creag Loisgte, north-west of Dalilea on Loch Shiel (28641 : 15 miles S. 30° W. of Kinlochmorar ; found by Professor Kennedy), and 1½ miles south-east of Resipol Farm on Loch Sunart (36846 : 19 miles S. 20° W. of Kinlochmorar ; found by the writer). All these rocks look very similar in the field and closely resemble the Arnipol calc-silicate ribs. Under the microscope they prove to be coarser in grain and much less rich in epidote and to contain hornblende of a dark-green colour. The writer regards them as possibly more highly metamorphosed equivalents of the Arnipol and Camastorsa calc-silicate ribs.

Cataclastic Mosaic of Sutured (Crenulate) Quartz-Grains

It has been stated that the most characteristic feature of the Sub-Moine psammitic rocks of the Morar Anticline is a cataclastic quartz-mosaic of highly inequigranular sutured (crenulate) grains with a marked undulose extinction (e.g. Plate XVII, fig. 6) ; and that, on the other hand, the Moine psammitic rocks are more feldspathic and have an even-grained granoblastic (round-grained) structure (1939, pp. 39, 40). These statements, *in a broad sense*, appear to be true.

The writer has, however, recognized cataclastic sutured quartz-mosaic (1) in slices of rocks of the *Upper Psammitic Group of the Moine* between Loch nan Uamh and Lochailort (36801 : Plate XVII, fig. 5) and on Eilean Ighe west of the Mallaig–Arisaig House outcrop of the Moine Striped and Pelitic Group (33421) ; and near the coast 1½ miles south-west of Glenuig House (36892–3 : 7 miles south by west of Arisaig) ; (2) in slices of rocks mapped as *Moine Lower Psammitic Group* on the coast south-west of Arisaig House (36793), and on the hill about a mile east of Mallaig (33657) ; and (3) in narrow *quartz-" lits ", in a slice from the Moine Lower Psammitic Group* on the shore south-west of Arisaig House (36795) *and in slices from the Moine Lower Striped Schists* on Ard nam Buth at the head of Loch nan Uamh (36802A), and near Arnipol cottage (36372 : an Arnipol type calc-silicate rib : Plate XVII, fig. 1).

Moreover, sutured quartz-mosaic is *not* present in some rocks mapped as Sub-Moine psammitic ; for instance : (1) at the top of

the *Outer Sub-Moine Psammitic Group* on the east side of the bay at Mallaigmore (36812); (2) just east of Loch an Nostarie (1 mile E. 40° S. of Mallaig: 36107); (3) in a "*Sub-Moine inlier*" (3 miles east of the large Morar Anticline "inlier") near Rudh' Ard na Murrach on the south shore of Loch Nevis, 1½ miles E. 15°.N. of Kylesmorar (33530–3); and in some rocks mapped with the *Main Striped Group of the Sub-Moine* (1) at Beasdale road-bridge 4 miles E. 15° S. of Arisaig (36790); (2) on the north of Loch Nevis almost a mile west of Glaschoille House (32132), and (3) just east of Rudh' Ard na Murrach (34224–6).

In the psammitic rocks of the Loch nan Uamh area, sutured quartz-mosaic becomes more prevalent north-westwards towards the core of the Morar Anticline; but its development does not come on abruptly, for although it is present in some of the rocks with which the calc-silicate ribs of Arnipol type are associated (e.g. 36807) it is absent in others (e.g. 36809A). The two slices just quoted represent rocks previously classed as Sub-Moine. A slice of adjacent Moine Lower Psammitic, in which a calc-silicate rib of Arnipol type is also intercalated, exhibits localized development of sutured quartz-mosaic (36804).

The presence or absence of sutured or crenulate quartz is thus not diagnostic either of Moine or Sub-Moine rocks. Further petrographical study may confirm the writer's present supposition that sutured quartz-mosaic is a characteristic product of local shear-tectonics in folded rocks, or in parts of folded rocks, that are poor in mica and have a fairly high quartz/feldspar ratio.

Foliation Oblique to Folded Bedding

Foliation, made obvious by orientation of micas, is said to be characteristically oblique to the bedding in Sub-Moine psammitic rocks; in Moine psammitic rocks, on the other hand, the foliation has been stated to be parallel to the bedding (1939, pp. 40, 41). Here, again, the statements are *broadly* true.

The writer, or Mr. T. R. M. Lawrie, has, however, found examples of oblique foliation (1) in highly folded *Moine Upper Psammitic rocks* between Loch nan Uamh and Lochailort (36801); (2) in the *Moine Lower Psammitic Group* at the head of Loch nan Uamh, and near the shore south-west of Arisaig House, in close proximity to Sub-Moine psammitic rocks, and (3) in the *rocks at the head of Loch nan Uamh, previously mapped as the outermost psammitic zone of the Sub-Moine*, in which calc-silicate ribs of the Arnipol type have been found. Moreover, foliation (defined by micas) oblique to the bedding has long been known in the Eilde Flags (psammitic Moine rocks) of the Glen Coe district (1916, p. 203).

In the hand-specimens of certain Sub-Moine psammitic rocks listed above as not containing sutured quartz-mosaic, foliation, defined by orientation of micas, is parallel to the bedding (33530, 33533), while in others the orientation of mica is rather haphazard (36107, 36812). In the case of rocks of the Main Striped Group of the Sub-Moine listed as not containing sutured quartz-mosaic, some hand-specimens show well-marked oblique foliation (34224–6) ; in another case (36790) indications of some oblique orientation of mica can be seen under the microscope. In another instance (32132) the wavy mica orientation indicates an approach to strain-slip cleavage.

The presence or absence of oblique foliation is thus not diagnostic either of Moine or Sub-Moine rocks. Moreover, it is clear that alignment of mica oblique to the bedding has been developed in folded rocks with or without a cataclastic sutured quartz-mosaic. The presence or absence of oblique foliation appears to depend simply on the type of tectonic movement to which the rocks concerned have locally been subjected. It is suggested that the prevalence of sutured quartz-mosaic and/or of obliquely oriented micas in the sedimentary rocks of the Sub-Moine core of the Morar Anticline may simply be due to tectonic conditions at a relatively low structural level.

It is only in the field that satisfactory observations can be made on the existence and local prevalence of oblique foliation. When the writer began working on the Moine/Sub-Moine boundary problem at the head of Loch nan Uamh he had hopes of being able to draw a boundary on the basis of the presence or absence of this feature, which here certainly becomes more prevalent in the direction of the core of the Morar Anticline. Both here, and on the coast south-west of Arisaig House, where a careful field study was also made, the local presence of intense folding and well-marked oblique foliation in the Moine Lower Psammitic Group made it impossible to use the oncoming of such foliation as an aid in defining the lower limit of Moine psammitic types adjacent to " Sub-Moine " psammitic types. The oncoming of intense folding and oblique foliation appears to be not abrupt, but transitional. At the head of Loch nan Uamh, where exposures are so good, there appears to be also a lithological transition, the proportion of mica (especially biotite) in these psammitic rocks decreasing at lower stratigraphical levels on passing north-west from rocks mapped with the Lower Psammitic Group of the Moine across others previously mapped as the outermost psammitic zone of the Sub-Moine.

Epidote

Dr. Richey and Professor Kennedy have stated (1) that in the Sub-Moine psammitic rocks and in the Sub-Moine Main Striped

Group, epidote is characteristically abundant; (2) that in the psammitic rocks it forms large yellow pleochroic crystals often with orthite centres; (3) that although epidote may be abundant in Moine Lower Psammitic rocks it is there colourless and forms tiny grains; and (4) that the striped rocks of the Moine Series [1] seldom, if ever, contain epidote (1939, pp. 40, 41).

The writer has not yet had time to study the large Survey collection of sliced rocks sufficiently to judge how far all these generalizations are justified. It can, however, be stated that epidote is prevalent locally, in small or relatively large grains, in striped rocks of Moine psammitic groups. For instance, (1) in "thinly bedded granulitic schists without false-bedding" mapped as the base of the Moine Lower Psammitic Group near Mallaigmore (1939, pp. 28, 30) epidote (pale, granular) is abundant (36813–4): these rocks are somewhat striped to semipelitic and one slice (36814) contains localized sutured quartz-mosaic; and (2) in striped rocks, verging on semipelitic, from a Moine psammitic belt on the shore of Loch Sunart at Torr Molach (1½ miles south-south-west of Salen and 21 miles south of Mallaig), where pale epidote is abundant in crystals as large as those characteristic of the Sub-Moine rocks of Morar (36852–4). Again, yellow epidote with distinct pleochroism [2] of varying intensity occurs locally in the Moine Series: e.g. 36268–9 from the Upper Psammitic of Eilean Ighe west of Arisaig, with relatively large crystals of yellow strongly pleochroic epidote; and 36816 from the Lower Psammitic Group east of Mallaig with yellow strongly pleochroic epidote in both relatively large and small crystals; see also footnote, p. 268.

The colour and size of epidote crystals is thus not diagnostic of Sub-Moine or Moine rocks.

HAEMATITE

One of the characteristic features of Sub-Moine rocks is said to be the presence of tiny patches of red haematite, mainly associated with muscovite. These little bright red patches, conspicuous in hand specimen, were also recognized by Mr. Eyles in the Lower Psammitic Group of the Moine Series (1939, pp. 39, 40).

The presence of haematite spots is thus clearly not diagnostic of Sub-Moine as opposed to Moine rocks, and in particular is of no value in distinguishing between the outermost psammitic zone of the Sub-Moine and the adjacent Lower Psammitic Moine.

[1] This statement may refer only to the *Striped and Pelitic Group* of the Moine Series.

[2] In Sub-Moine psammitic rocks the depth of colour of epidote is very variable in thin section, and it is sometimes difficult to detect any pleochroism.

Summary and Conclusions

In this paper the writer deals with certain mineralogical and textural features found in the Moine and Sub-Moine Series of western Scotland, viz. garnet-zoisite calc-silicate ribs, non-garnetiferous epidotic calc-silicate ribs, sutured (crenulate) quartz-mosaic, foliation oblique to folded bedding, and the presence of abundant yellow epidote and of spots of haematite. The garnet-zoisite calc-silicate ribs have been claimed by Dr. Richey and Professor Kennedy as diagnostic of parts of the Moine Series. For the non-garnetiferous epidotic calc-silicate ribs, which have not previously been described, the name " calc-silicate ribs of Arnipol type " is suggested. These ribs occur in adjacent groups of rocks that have been mapped with the Lower Striped Schists and the Lower Psammitic Group of the Moine and with the outermost psammitic zone of the Sub-Moine.

The above-mentioned features, other than calc-silicate ribs, have been claimed as characteristic of the Sub-Moine Series, and most of them have been described in such a way that a reader may be given the impression that they are regarded as diagnostic of that Series, and by implication diagnostic of a sudden change in sedimentary facies, and of a different state of metamorphism, in the Sub-Moine as compared with the Moine Series of Morar (Richey and Kennedy, 1939).

The writer agrees that garnet-zoisite calc-silicate ribs are diagnostic of parts of the Moine Series, and that they do *not* occur in the Lower Psammitic Group—where they would be most useful in helping to distinguish this group from the underlying outermost psammitic zone of the Sub-Moine. He claims that the other features (exclusive of calc-silicate ribs of Arnipol type), although particularly characteristic of the Sub-Moine core of the Morar Anticline [1] are not infrequently absent from the core rocks,[2] and *can all be found locally in the adjacent Moine Series.* For diagnostic purposes these criteria are therefore valueless.

The writer believes that :—

(1) Failure to realize that no single feature, and no combination of features, is *diagnostic* of the Sub-Moine metamorphic sediments of the Morar Anticline, led Dr. Richey and Professor Kennedy to underestimate the difficulty of distinguishing between Lower Psammitic Moine and adjacent older (" Sub-Moine ") psammitic rocks.

(2) There are rock-types indistinguishable from Sub-Moine psammitic well within the Moine Lower Psammitic Group east of Mallaig—as Mr. V. A. Eyles was the first to point out.

[1] Where, it is suggested, those produced by folding may simply be due to tectonic conditions at a relatively low structural level.

[2] As is also the case in the Rudh' Ard na Murrach " inlier ".

(3) At least locally, it is impossible to delimit Lower Psammitic Moine and adjacent rocks mapped as Sub-Moine outer psammitic zone : for instance, just east of Loch an Nostarie ; and at the head of Loch nan Uamh. Hence, there is doubt as to the reality of the transgression of the base of the Moine across the outermost psammitic zone of the Sub-Moine (1939, p. 44).

(4) At least locally, no sudden change in lithology or in tectonic or metamorphic state can be detected on passing downwards from the Lower Psammitic Group of the Moine towards the core of the Morar Anticline.

The observations on which the last belief is based have been made mainly in the area between the head of Loch nan Uamh and Lochailort, where there are very full exposures of the outermost psammitic zone of the Sub-Moine succeeded south-eastwards by all the groups of the Moine. The evidence for linking all the sedimentary rocks of this area in one series [1] is partly stratigraphical, partly tectonic and mineralogical. The stratigraphical evidence includes (1) false-bedding in the outermost psammitic zone of the Sub-Moine and in the Upper Psammitic Group of the Moine ; (2) intercalation of calc-silicate ribs of Arnipol type, not only in rocks formerly classed as Sub-Moine, but also in immediately adjacent rocks of the Lower Psammitic Group, and of the Lower Striped Schists, of the Moine ; (3) *gradual* increase in the proportion of mica on passing from lower to higher horizons in the outermost Sub-Moine psammitic zone. The tectonic and mineralogical evidence includes (1) recognition of intense minor folding of the same " style ", not only in rocks mapped as psammitic Sub-Moine (including those containing calc-silicate ribs of the Arnipol type), but also locally in the Moine Lower Psammitic Group and widely in the Moine Upper Psammitic Group ; (2) recognition of cataclastic sutured quartz-mosaic and of foliation oblique to folded bedding, not only in the Sub-Moine rocks last mentioned, but also locally in the Moine Lower Psammitic Group and in the Moine Upper Psammitic Group ; (3) *gradual* increase in the prevalence of sutured quartz-mosaic and oblique foliation on passing north-westwards from the Lower Psammitic Group of the Moine towards the core of the Morar Anticline.

The writer has deliberately abstained from dealing with the interior of the Sub-Moine core of the Morar Anticline and with Professor Kennedy's evidence for recumbent folding. Nevertheless, in view of the facts and inferences summarized above, it seems prudent to keep

[1] They were originally mapped as one series by Dr. J. B. Simpson ; and, at an early stage, the " Sub-Moine " psammitic rocks in which Professor Kennedy records false-bedding were assigned by Kennedy himself to the Moine Lower Psammitic Group.

FIG 1

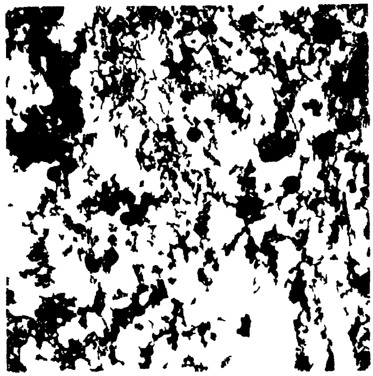


FIG 2

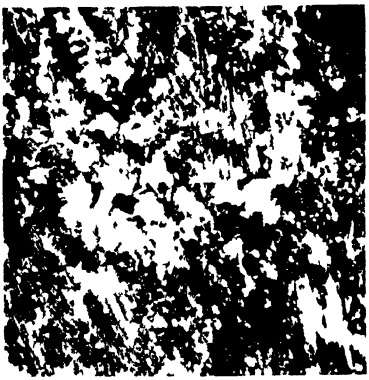


FIG 3

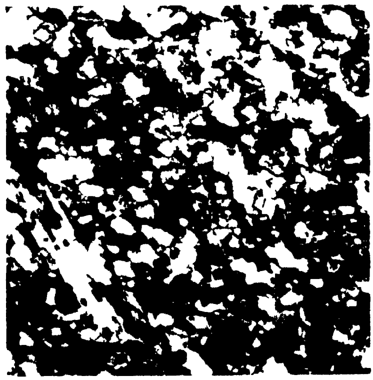


FIG 4

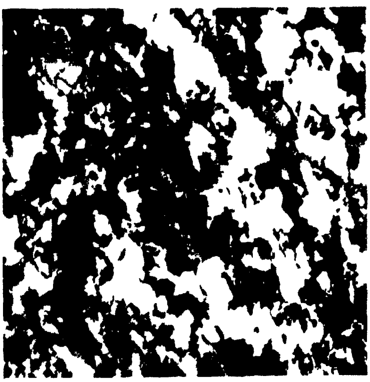


FIG 5

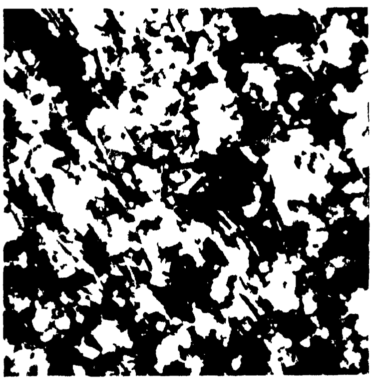


FIG 6

MOINE AND "SUB-MOINE" ROCKS OF THE LOCH NAN UAMH AND LOCH SUNART AREAS

in view the possibility that all the metamorphic " Sub-Moine " sediments of Morar constitute a lower part of the Moine Series associated with hornblendic orthogneisses (cf. 1948, p. 20).

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EXPLANATION OF PLATE

ALL PHOTOMICROGRAPHS MAGNIFIED 12·5 DIAMETERS

FIG. 1.—Calc-silicate rib of Arnipol type in Moine Lower Striped Schists (Slice No. 36372). Roadside 10 yards south of Arnipol cottage. Ordinary light. In the photo epidote is dark grey, and quartz and feldspar white. The central vertical white band is a localized quartz-" lit " with cataclastic sutured mosaic structure.

FIG. 2.—Calc-silicate rib of Arnipol type in the outermost psammitic zone of the Sub-Moine (Slice No. 36783). Roadside 680 yards W. 5° N. of Arnipol cottage. Ordinary light. In the photo epidote is dark grey and quartz and feldspar white.

FIG. 3.—Very pale green porphyroblastic hornblende in calc-silicate rib in Moine Lower Striped Schists. Roadside 70 yards E. 15° S. of Arnipol cottage (Slice No. 36803). Nicols crossed. The acicular mineral aligned " N.W.–S.E." and " N.N.W.–S.S.E." is hornblende ; in the extreme " south-east " corner a broader stumpy crystal, with ragged ends, appears white in the photo. The white-grey-black mosaic consists mainly of quartz and feldspar. This rib contains no epidote ; but similar hornblende occurs in epidotic calc-silicate ribs in Moine and " Sub-Moine " rocks.

FIG. 4.—Very pale green porphyroblastic hornblende in calc-silicate rib of Arnipol type in Moine psammitic rocks (Slice No. 36857). North shore of Loch Sunart about 175 yards south-south-west of Camastorsa. Nicols crossed. A ragged rectangular section of porphyroblastic hornblende about 2 mm. long (white in photo) crosses the " south-west " corner of the picture. The white-grey-black mosaic consists mainly of quartz, feldspar, and epidote or epidote/clinozoisite.

FIG. 5.—Cataclastic sutured quartz-mosaic in folded psammitic rock of the Moine Upper Psammitic Group (Slice No. 36801). Roadside 870 yards S. 26° E. of Arnipol cottage. Nicols crossed. Consists largely of quartz and feldspar with a little mica. In the photo the foliation trends approximately " N.W.–S.E." Compare Fig. 6.

FIG. 6.—Cataclastic sutured quartz-mosaic in folded psammitic rock of the outermost psammitic zone of the " Sub-Moine " (Slice No. 36786A). Roadside north of the head of Loch nan Uamh, a little west of the north end of the railway viaduct. Nicols crossed. Consists largely of quartz and feldspar with a little mica. In the photo the foliation trends approximately " N.W.–S E." Compare Fig. 5.

Photomicrographs by W. Fisher.

The Age of the Neptunian Dyke at Hazler Hill

By ISLES STRACHAN, JOHN TEMPLE, and ALWYN WILLIAMS

DURING the Easter Field Meeting of the Sedgwick Club, portions of the Neptunian dyke at Hazler Hill, near Church Stretton, were collected and brought back to Cambridge for further examination. The material consisted of a buff-coloured, sandy mudstone with scatters of facetted pebbles of quartzite and igneous material, including weathered rhyolite, up to a centimetre in diameter. The material proved to be richly fossiliferous and the following fauna was obtained which, we believe, throws some light on the age of these sand-filled fissures :—

Trilobites :	*Salterolithus* cf. *harnagensis* Bancroft.
	S. cf. *harnagensis* var. Bancroft (1929, p. 80). (fairly common)
	S. cf. *sp.* Bancroft (1929, p. 81). (occurs)
Brachiopods :	*Dolerorthis sp.* (occurs)
	Corineorthis sp. nov. (common)
	Glyptorthis sp. (occurs)
	Dinorthis aff. *flabellulum* (J. de C. Sowerby). (fairly common)
	Cliftonia andersoni Reed. (occurs)
	? *Triplesia sp.* (occurs)
	Orthorhynchula sp. (occurs)
	Rostricellula sp. (fairly common)
	Sowerbyella aff. *sericea* (J. de C. Sowerby) var. *soudleyensis* Jones. (common)
	Dalmanella small sp. (common)
	Harknessella (*Smeathenella*) aff. *harnagensis* Bancroft. (fairly common)
	Harknessella ? *vespertilio* (J. de C. Sowerby) (occurs)
Ostracods :	*Tetradella scripta* Harper. (very common)
	Tetradella sp.
	Ulrichia cf. bicornis (T. R. Jones). (very common)
	Primitia cf. nana T. R. Jones. (common)
Others *:*	Bryozoa. (very common)
	Lepidocoleus cf. *suecicus* Moberg. (occurs)
	Crinoid ossicles. (very common)

All the trilobites collected have been here referred to *Salterolithus* Bancroft (1928, p. 78 *et seq.*); the latter has been characterized by its author as having three rows of pits external to the girder on the lower lamella, although his most fully described species *S. harnagensis* has only two, and is in some respects comparable with *Broeggerolithus* Bancroft. The majority of the dyke specimens show a very poorly developed third row external to the girder (E3) and resemble the variety of *S. harnagensis* mentioned by Bancroft (1928, p. 80). A form with well-developed E3 was also collected (*S.* cf. *sp* Bancroft above).

The brachiopod listed above as a new species of *Corineorthis* Stubblefield, is a distinctive little form which has possibly been noted time and again (*Mem. Geol. Surv.*, 1938, Shrewsbury District, p. 85 ; and Bancroft, 1945, pp. 182 and 230) as *Schizophorella* Reed. It is very close to *Corineorthis salteri* (Davidson) (1871, p. 255, pl. xxxvi,

figs. 31–34) but without the fold and sulcus, and with a less well-developed dorsal muscle scar. The form is provisionally referred to *Corineorthis* on the strength of the Plectorthid cardinalia and general disposition of the valves. Actually the ventral muscle scar is smaller and the adductor track much wider than in *Corineorthis* spp (e.g. the genotype *C. decipiens* Stubblefield).

Smeathenella Bancroft is here referred to as a sub-genus of *Harknessella* Reed, contrary to Bancroft (1945, p. 231) because in our opinion the term embraces a group of low convexity Harknessellids and the internal differences between them and *Harknessella* s.s. are only a reflection of the differences in contour. *Dalmanella* small *sp.* as recorded here is probably conspecific with *Wattsella* small *sp.* (Bancroft, 1945, p. 237), *Wattsella* Bancroft being a synonym of the earlier founded *Dalmanella* Hall and Clarke (see Öpik, 1932, and Cooper, 1943).

At least four species of ostracods are present. The specimens of *Tetradella scripta* Harper show considerable range in size as Harper noted (1948, p. 348) but the other species of *Tetradella* present is quite distinct from anything described in that paper. *Ulrichia bicornis* (Jones) and *Primitia nana* Jones are recorded only from the Harnage Shales (*Mem. Geol. Surv.*, Shrewsbury, 1938, p. 86) and closely allied, if not identical, forms are found in the dyke. T. R. Jones unfortunately gives no size for *U. bicornis*, but judging from his figure (1855, pl. vi, fig. 23), his specimens were probably considerably larger than those found here. As already noted, however, considerable variations have been observed in other species and the identity of the forms is here assumed.

The presence of undoubted species of *Salterolithus* means that the dyke is either of Harnagian or Soudleyian age (Bancroft, 1938 *et seq.*) and the absence of *Rafinesquina expansa* together with the general assemblage of Brachiopods (compare Bancroft, 1945, p. 182) and the Ostracods (compare *Geol. Surv. Mem.*, Shrewsbury, 1938, p. 86) is certainly suggestive of the Harnagian.

Of these Brachiopods the small form which we refer to *Harknessella* (*Smeathenella*) aff. *harnagensis* is very finely ribbed. Bancroft (1945, p. 235) describes a form from Cressage with very fine ribbing which is characteristic of the basal Harnagian. Other species of this age include, according to Bancroft (1945, pp. 182, 230, 237, etc.), *Schizophorella sp.*, *Schizophorella salteri*, *Cliftonia andersoni*, *Harknessella* aff. *vespertilio*, *Dinorthis sp.*, *Dolerorthis sp.*, Rhynchonellids, small *sp.* of *Wattsella* (= *Dalmanella*), and *Sowerbyella sp.* Our Corineorthid (which is possibly conspecific with his *Schizophorella sp.*), small *sp.* of *Dalmanella* and *Sowerbyella sp.* are very common, while *Cliftonia andersoni*, *Dolerorthis sp.*, *Dinorthis sp.*, and Rhynchonellids

(*Rostricellula sp.* and *Orthorhynchula sp.*) are recorded. The similarity of these faunas would indicate a Basal Harnagian age for the latter.

Dr. Bulman has drawn our attention to the implication in the discussion on the Hoar Edge and Harnage groups in the *Mem. Geol. Surv.*, Shrewsbury District, 1938, which rather substantiates the above conclusion. Sandstones and shales (which Bancroft regards as basal Harnage) lying immediately above the *Harknessella subquadrata* Limestone near Harnage Grange, contain *Sowerbyella sp.*, *Dinorthis flabellulum*, and " *Orthis* " aff. *salteri* but with slight differences (op. cit., p. 85). This latter species may be conspecific with the Corineorthids obtained from the dyke. Also, in the discussion on the Harnage group (op. cit., p. 86) it was postulated that the grit, a few feet thick, which Lapworth termed the " Transition Bed ", lying at the base of the group, represented the break which on graptolitic evidence was believed to occur between the upper beds of the Hoar Edge Grit and the Harnage Group. The fauna of this " Transition Bed " is scanty but includes *Tetradella complicata*, which we suggest was used *sensu lato*, as the species-group is referred to in the same sentence and which probably includes the forms we refer to the recently erected *T. scripta*. *Sowerbyella* with ventral muscle scar intermediate between *S. antiquata* and *S. sericea* var. *soudleyensis* was also collected (op. cit., p. 86). Ours are definitely smaller than the latter variety, the ribbing is less well-differentiated, the muscle scars likewise smaller, and they are probably representatives of a similar intermediate stage of development.

The conclusion drawn, then, is that the Neptunean dyke was filled in very early Harnage times by a transgressive sea and that it is possibly equivalent to the " Transition Bed " between the Hoar Edge Grit and the Harnage Shales.

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The Chalky Boulder Clays of Norfolk and Suffolk

By D. F. W. Baden-Powell

The Glacial Succession

In the past there have been two main lines of approach to the glacial problems of East Anglia :—

(1) Attempts to find out the number of glacial and interglacial deposits ; and

(2) The direction or directions of ice-movement as shown by the constituent materials.

A fresh investigation of the boulder clays has been undertaken, combining as far as possible these two points of view, with special attention (so far) to the varieties of " Chalky Boulder Clay " (see Baden-Powell, 1948, pp. 287–8).

The general glacial succession in the area has been established now for many years, but during the nineteenth century knowledge on this subject accumulated very slowly. As early as 1877 James Geikie suggested that the east of England had been affected by four glaciations (Geikie, 1877, p. 393), but his sequence was largely neglected at the time. It was admitted that the coastal sections at Gorleston and Corton showed two boulder clays separated by marine sand, and the lower boulder clay was found to contain less chalk than the upper. The lower became known by a variety of names, including Cromer Till, Norwich Brickearth, North Sea Drift, and (erroneously) Contorted Drift, and the upper as Chalky Boulder Clay, owing to its greater content of chalk. In the meantime, a brown boulder clay at Hunstanton was gradually recognized as differing from either of the other two, and as being later than them, so that, in fact, three glaciations were known in the district ; the North Sea Drift (" Lower Glacial "), the Great Chalky Boulder Clay (" Upper Glacial "), and the Brown Boulder Clay at Hunstanton.

Further investigation led to the discovery that " the " Chalky Boulder Clay varies greatly in the amount of Jurassic material included with the ever-present chalk and flint, and a number of investigators suggested that there might be two Chalky Boulder Clays (F. J. Bennett, 1884, pp. 13–16 ; 1884, pp. 7–12 ; 1891, pp. 61–2 ; J. W. Gregory, 1898, pp. 454–5 ; G. Slater, 1907, p. 190 ; P. G. H. Boswell, 1912, pp. 230–1 ; J. Reid Moir, 1920, p. 223 ; J. Reid Moir in P. G. H. Boswell and I. S. Double, 1922, p. 312 ; P. G. H. Boswell and J. Reid Moir, 1923, pp. 243–4 ; G. Slater, 1927, p. 168 ; F. W. Harmer, 1928, p. 114 ; P. G. H. Boswell, 1929, p. 38 ; P. MacClintock, 1933, pp. 1049–1050 ; and H. L. Movius, 1942, p. 26). Some of these authorities thought it possible that one kind of chalky boulder clay could be correlated with the Cromer Till, or that another kind could

be the same age as the Hunstanton Boulder Clay, but it was later shown by Boswell (1931, pp. 93–7 ; 1932, table facing p. 88 ; and 1936, pp. 157–160) that both the chalky boulder clays are distinct from both the Cromer Till and the Hunstanton Boulder Clay, and that there are at least four different boulder clays in East Anglia.

In the meantime J. Solomon (1932, p. 244) had found evidence for the products of these four glaciations in the Cromer area, and the correlation of these with some other parts of East Anglia was later confirmed by tracing the marine Corton Beds over a wide area (J. Reid Moir and D. F. W. Baden-Powell, 1938, p. 912 ; and 1942, pp. 210–11). The three boulder clays of West Suffolk investigated by T. T. Paterson (1937, p. 89 ; 1939, p. 822 ; and 1940, p. 2), and F. E. Zeuner's analysis of the problem of two chalky boulder clays (1945) will be discussed in a later part of the present paper.

In summarizing present ideas on the sequence, the difficulties of nomenclature are considerable. But as the Lower Chalky Boulder Clay is typically developed near Lowestoft, this will be called the Lowestoft Boulder Clay in the present paper, and as the Upper Chalky Boulder Clay was first recognised in the Gipping Valley near Ipswich, the term Gipping Boulder Clay will be used here for that deposit. The other main glacial deposits of the area have long-established names. The succession is as follows :—

8. Hunstanton Boulder Clay.
7. March Gravels (marine).
6. Gipping Boulder Clay (Upper Chalky Drift).
5. Hoxne Interglacial.
4. Lowestoft Boulder Clay (Lower Chalky Boulder Clay).
3. Corton Beds (marine).
2. Norwich Brickearth. } (North Sea Drift.)
1. Cromer Till. }

It will be noticed that such terms as " Chalky-Kimmeridgian " and " Chalky-Jurassic " Boulder Clays do not appear in this list. These names have been avoided, because they refer only to the character of a glacial clay at a particular place and not to its age. The name " Contorted Drift " is also not used here, because any deposit contorted by glacial action could be so called, and in the past it has been misleading as a stratigraphical term. There is some evidence now that the North Sea Drift can be divided into two independent glacial stages, but further investigation is needed to prove this.

Directions of Ice-Movement

The establishment of the glacial succession in East Anglia in the past has depended partly on the recognition of interglacial deposits, such as the Hoxne Brickearth or the Corton Beds, and partly on the

attempted correlation of boulder clays from one section to another. But certain facts have to be assumed in order to assure the best chance of success for the glacial correlations. If boulder clay is considered to be the product of land-ice, which seems to be the case with most of the East Anglian boulder clays, its contents should show the nature of the outcrops over which the ice has passed and give an idea of the direction in which the ice has moved. On the assumption that ice tends to travel in fairly straight lines rather than sharp curves in flat country like East Anglia, successive boulder clays in section will show by their content any successive changes in ice-direction which have occurred. In this way a glacial sequence can be made out, and boulder clays can be used for correlation over long distances. This method has been employed for many years in other parts of Britain (Eastern Scotland, Northern Ireland, etc.), and it is surprising that it has not been applied more thoroughly in East Anglia.

It must be remembered, however, that the glacial deposits of Norfolk and Suffolk are enclosed on the west and north-west sides by outcrops of the Chalk, and because much of the ice which formed the glacial deposits of this area had crossed the outcrops of this formation, most of the boulder clays are chalky to a greater or lesser extent and also contain much flint. Rarer rock-fragments, which might have helped to distinguish particular layers in the glacial series, are therefore masked by this content of chalk and flint ; this is probably one of the chief reasons why the zoning of the East Anglian drift by its contents has been found so difficult.

Previous work which has been done on the directions of ice-movement has led to somewhat contradictory results. Bennett (1884, pp. 7–8 and 1891, p. 62) thought that in West Suffolk a pale sandy boulder clay was derived from the north-west, and that a darker bluish boulder clay in the same district came from the north-east ; he also thought these two deposits were contemporaneous. But H. B. Woodward (1885, pp. 112 and 125) and later Harmer (1904, p. 509) believed that the Jurassic material in the darker clay pointed to a north-westerly origin, whilst the Cromer Till was thought to have come from the north-east. Hill (1902, pp. 179–184) had also come to the conclusion that some of the boulder clay between Lowestoft and Bury St. Edmunds had come from the west or north-west, and Harmer (1902, pp. 464–5) agreed with this, especially as erratics of Carboniferous rocks were found with those of Jurassic and Cretaceous origin.

In a later series of papers, Harmer (1907, p. 571, and 1928, pp. 102–114) proved clearly that the ice-movement from the west and north-west occurred during Chalky Boulder Clay times, and that Lias (Grantham Marlstone), Lincolnshire Oolite, Oxfordian, Corallian and

Kimmeridgian materials, Neocomian Sandstone, Red Chalk, and special types of White Chalk and flint, could all be recognized as having been brought from Lincolnshire across Fenland into East Anglia. He developed a theory that the Chalky Boulder Clay Ice, on reaching Fenland, fanned out eastward into East Anglia, southward towards London, and westward towards the valleys of the Trent, Nene, and Great Ouse. In order to account for anomalies which were found west of the Fens, he had to resort to the idea of cross-currents in the ice.

Harmer's pioneer work on ice-direction in this part of England is the foundation of all later developments, but it suffered from two defects: (1) the idea of cross-currents was unsatisfactory, and (2) Harmer was dealing mainly with one rather than two Chalky Boulder Clays. Now if Harmer's well-known map (in his 1928 paper), showing the different kinds of drift, is examined, it will be seen that the symbol for Chalky-Kimmeridgian Boulder Clay is found over an isolated area of Suffolk, surrounded on three sides by Chalky Boulder Clay. The distribution of the Chalky-Kimmeridgian and that part of the Chalky Boulder Clay in southern Norfolk agree with derivation from the west, but the Chalky Boulder Clay in the belt of country from King's Lynn to Ipswich is quite anomalous. Solomon (1932, pp. 317–18) attempted to solve this problem by suggesting that the lower layers in the ice contained much Jurassic material and failed to surmount the Chalk escarpment, except where it is lowest around Thetford, but this does not explain how the Chalky-Jurassic and Chalky types of boulder clay can be seen together (e.g. near Ipswich), nor the presence of chalk in the boulder clay west of the Chalk escarpment, as in Fenland. It is most unlikely that the ice would have taken these divergent directions at any one time, and the discovery that there are two chalky boulder clays began to suggest a solution. Moir and Boswell showed in various papers that the ice-movement was from west and north-west during the Lower Chalky Glaciation, although the direction during the Upper Chalky Glaciation had yet to be worked out in detail.

The Contents of the Chalky Boulder Clays

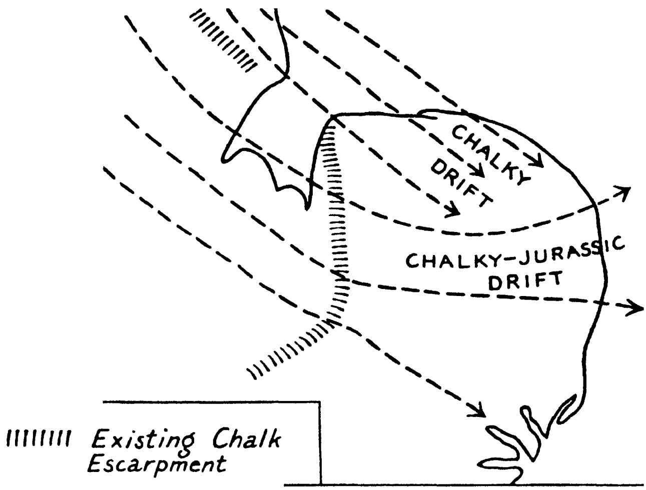
My main problem, then, in starting work on these boulder clays, was to find out the ice-direction for the Upper Chalky Glaciation in comparison with that during the Lower Chalky Stage. Special attention has therefore been given to these two formations, and further work is needed on the Cromer Till and Hunstanton Boulder Clay in order to prove the directions from which their materials have been transported. The method employed was to examine as many boulder clay sections as possible, to see whether the matrix consists mainly of

Chalk or of Jurassic materials. Erratics were also collected when *in situ* in the boulder clays, but they are only considered as evidence supporting the general observations on types of matrix which was the main object of the field-work. In this way empirical data were accumulated on the rock-types assembled in each stratigraphical zone, and it has not yet been found possible to determine the exact provenance of all the erratics, some of which are, in any case, derived from earlier glacial horizons. I would like to take this opportunity to thank Dr. W. J. Arkell for his identification of fossils among the erratics ; Dr. R. H. Rastall and Dr. J. V. Harrison for their help with the petrological problems ; and Mr. W. E. Smith for collecting samples of Derbyshire igneous rocks for comparison with certain erratics.

The first fact confirmed in the field was that the chalky boulder clays are mainly divided into two types : a dark type consisting essentially of chalk and other pebbles in a matrix of sand and Jurassic clay, and a pale type which consists of pebbles of chalk, flint, and other rocks in a sandy chalky matrix. It was found difficult to confirm that the dark Jurassic type is lower stratigraphically than the pale chalky type, as the two are seldom seen in direct superposition. The main locality in southern Suffolk where the pale chalky type overlies the dark Jurassic type is the Claydon Cement Works, north-west of Ipswich, and this section was recently visited during a Geologists' Association Field Meeting (C. D. Ovey and W. S. Pitcher, 1948, pp. 25–6). It is probable that gravels at Darmsden, north of Claydon, occur in stratigraphical position between these two boulder clays, but excavation is needed to prove this. Records by past observers suggest that there is considerable evidence that the pale type is younger than the dark type near Ipswich, and over a wider area Mr. Reid Moir's work in particular showed that the main horizon for certain types of Acheulian and Clactonian implements, for instance at Derby Road, Ipswich, at Hoxne, and at High Lodge, is intermediate in age between these two boulder clays. The evidence for this is cumulative rather than precise at any one section. Incidentally, my own field-work produced many examples of erratics occurring in the pale boulder clay which appeared to be derived from the dark boulder clay, but no examples were found of the reverse.

The Lowestoft Boulder Clay.—The dark type of clay with much Jurassic material is typically developed around Lowestoft, especially in the coast section at Corton, where it rests on the marine Corton Beds. It can also be seen resting on the Corton Beds at the brickworks west of the coast road a mile south of Pakefield ; directly on Cromer Till at Somerleyton brickworks, and the base of the dark boulder clay can also be seen on Corton Beds at Lound, and at the most north-easterly of the three sandpits east of Bungay. Unfortunately,

all these inland pits were disused at the time of my visits (1947), and the sections are deteriorating. The dark boulder clay shows identical characters all over this area, and the " Lowestoft Boulder Clay " is therefore a convenient name for it. The matrix consists of a mixture of Jurassic Clays and of sand, and is either dark blue or dark brown, according to its degree of weathering. The commonest erratics are hard chalk, followed in approximate order of frequency by flint ;

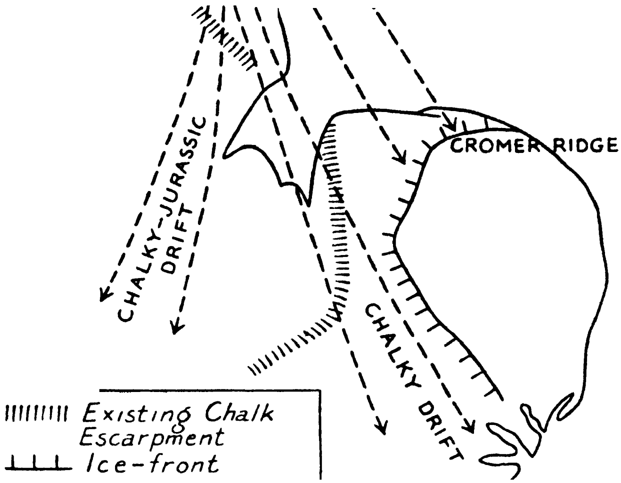


TEXT-FIG. 1.—Direction of Ice-movement during the Lowestoft (Lower Chalky) Glaciation.

Jurassic rocks and isolated fossils ; Neocomian sandstone ; sandstones, quartzites and vein quartz, probably from the Bunter ; and finally, non-porphyritic basalt, dark blue limestone, and ? Millstone-Grits, all possibly from the Southern Pennines. Small bits of Red Chalk occur rarely. No metamorphic or igneous rocks (apart from the basalt) have been found *in situ*, except one small pebble of schist at Pakefield, which could be derived from the underlying Corton Beds.

These characteristics are found over a much wider area than the Lowestoft district, and a deposit identical with the Lowestoft Boulder Clay was examined at the Claydon Cement Works, near Ipswich ; at Bawsey, east of King's Lynn ; at Roydon, west of Diss ; at Hoxne ; and at Darmsden, north-west of Ipswich. The details of the materials collected from this boulder clay are summarized in Table I. The distribution of boulder clay of Lowestoft type at the localities mentioned is in keeping with Harmer's idea of a general ice-movement south-east across Lincolnshire and continuing east and south-east into East Anglia (see Text-fig. 1 of the present paper). The Southern Pennine district is a possible source for this ice-sheet.

The Gipping Boulder Clay.—The pale type of boulder clay is found in its typical form near the Gipping Valley, and is therefore referred to here as the "Gipping Boulder Clay". The matrix is a mixture of chalk and sand, with some pale brown clay, and the erratics consist of flint, hard and soft chalk, Red Chalk (common), Bunter sandstones and quartzites, porphyrites of Old Red Sandstone types, various felspathic grits, and a rhomb-porphyry has been found by Dr. Tomlinson almost,



TEXT-FIG. 2.—Direction of Ice-movement during the Gipping (Upper Chalky) Glaciation.

but not quite, *in situ* in this deposit at Bolton's pit, Ipswich. Rarer Jurassic fossils, basalt, ? Carboniferous Limestone, and ? Millstone Grit also occur, but these are believed to be derived from the earlier Lowestoft Boulder Clay. Some of the flint has a blue-and-white "basket-work" patina which has not yet been seen *in situ* in the Lowestoft Boulder Clay. The pale boulder clay weathers quite differently from the dark into an unbedded unsorted boulder-gravel, of which the matrix is usually highly ferruginous. In this form it has usually been completely decalcified. The distribution of the contents of the Gipping Boulder Clay as seen during recent field-work is summarized in Table I.

The area of outcrop of the Gipping Boulder Clay is more restricted than that of the Lowestoft Boulder Clay. It was studied near Ipswich at the Claydon Cement Works, Bramford Works, at Bolton's (= Dales Road) Brickworks, and at a number of other pits within a few miles of the city, including Darmsden. In its weathered form it is believed to have been represented by a gravel above the brickearth at Derby

Road, Ipswich (P. G. H. Boswell and J. Reid Moir, 1923, pp. 243–4). Pale boulder clay very like the Gipping type is also common in north-west Suffolk and west Norfolk. It was examined by me at West Row, west of Mildenhall; High Lodge, east of Mildenhall; West Stow and Elveden, south-west of Thetford; Knettishall Heath, West Harling Heath, Garboldisham Heath, and Quidenham Brickworks, all between Thetford and Diss; and in its weathered form at Hoxne Brickworks. Small sections have also been seen at many other places, but this deposit was not seen east of a line running approximately from Quidenham by Hoxne to Ipswich, and this line seems to have been the site of an ice-front at this stage (Text-fig. 2). To the east of this line, the place of this boulder clay is taken by Cannon-shot-like gravels, which are sometimes sufficiently bedded to be outwash gravels from this ice-front.

The Gipping Boulder Clay is a dirty-white colour on its weathered face in the pits, but if this is hacked off, the inside of the clay is yellowish to khaki colour. In this pale form it is readily distinguishable from the Lowestoft Boulder Clay. But boulder clay is sometimes seen which is intermediate in colour between the pale khaki of the Gipping type and the dark brown of the weathered form of the Lowestoft type (especially at West Harling Heath, east of Thetford). Paterson (1937, p. 89) has suggested that this brown colour is due to earlier brickearth picked up and incorporated in the ice, and this seems to me the correct explanation. The boulder clay at the base of the Brundon section near Sudbury is this intermediate colour, and if the conclusions reached in the present paper are correct, the boulder clay at Brundon belongs to the Gipping glaciation, because of the occurrence in it of O.R.S. porphyrite (D. F. W. Baden-Powell in J. Reid Moir and A. Tindell Hopwood, 1939, p. 30). Some of the sections mentioned above are in the area investigated by Paterson, and therefore act as a link between his chronology and that suggested here.

The direction taken by the ice which brought this Gipping Boulder Clay has obviously been different from the earlier north-west to south-east movement. As the Gipping Boulder Clay contains much more chalk than the other, the later ice has presumably crossed a greater outcrop of Chalk than the earlier, and this would have been the case if it came from a more northerly direction than the Lowestoft ice, along the strike of the Chalk between Hunstanton and the Thetford area. Such a direction of movement is confirmed by the O.R.S. porphyrites and other erratics, which were brought along the present site of the East Coast from the north. The rhomb-porphyry at Ipswich and probably also the nordmarkite at Brundon (not actually *in situ*) would also fit this hypothesis, as the Gipping Ice could have picked up these rocks, and perhaps the O.R.S. as well, from some earlier

drift off the present site of the East Coast (Text-fig. 2). It is probable that many of the Scottish and Scandinavian erratics of the Cambridge area, especially at the Traveller's Rest pit, were introduced at this Gipping stage, though, according to Paterson some Scottish rocks were also brought at an earlier stage (possibly Cromer Till). This hypothesis of a later Gipping Ice-sheet coming from a more northerly quarter than the earlier Lowestoft Ice-sheet explains the distribution of these types of drift better than Harmer's suggestion of fanning-out and cross-currents of a single ice-sheet, and is strongly supported by such evidence as there is in Suffolk of superposition.

Correlation with the Cromer Sequence.—The extreme chalkiness of the Gipping Boulder Clay in southern Suffolk has been explained as the result of the Gipping Ice having travelled south along the strike of the Norfolk Chalk. This leads one to question whether a similar effect can be seen in the Lowestoft Boulder Clay which was brought from the north-west. Harmer has already shown that the Chalky-Jurassic type of boulder clay along the Norfolk-Suffolk border gives place to intensely chalky boulder clay farther north in Norfolk, and the reason is obvious. Part of the Lowestoft Ice-sheet brought Jurassic rocks from the neighbourhood of Lincoln to northern Suffolk at the same time as another part of the same ice-sheet brought chalk from the Lincolnshire Wolds to Norfolk, the north-west to south-east direction of movement being along the strike of the Lincolnshire Chalk. Thus, the intensely chalky boulder clay of much of Norfolk is due to ice which has travelled along the outcrop of the Lincolnshire Chalk at the earlier Lowestoft Stage (Text-fig. 2), whereas the intensely chalky boulder clay of western Suffolk is due to ice which has moved along the outcrop of the Norfolk Chalk at the later Gipping Stage (Text-fig. 1). This hypothesis is supported by the stratigraphy near Cromer, so far as it can be made out in spite of the contortions, as intensely chalky boulder clay is found resting directly on presumed Corton Beds near Cromer (Baden-Powell and Moir, 1942, pp. 213–214), whereas at Corton, the Corton Beds are succeeded by Chalky-Jurassic boulder clay. In both areas these boulder clays are succeeded by beds belonging to the Hoxne Interglacial. This explanation of the different boulder clays laid down by the Lowestoft Ice helps to make correlation possible between the four main glaciations in Solomon's area around Cromer with the four glaciations of the remainder of East Anglia (Table II).

The Chalky Boulder Clay of northern Norfolk has been examined in many sections, including pits east of East Runton, at Weybourne, and at Cawston, as well as at small exposures in the Cromer cliffs. Its general lithology is similar to the later Chalky Boulder Clay of Suffolk, consisting mainly of chalk and flint erratics in a matrix of

sandy chalk. The two deposits, though differing in age, are so alike in their general appearance that it has been found difficult so far to distinguish between them in north-western Norfolk. A collection of erratics has been made from the chalky boulder clay of Lowestoft age in north-eastern Norfolk, however, and shows some differences from the later deposit in Suffolk. The chief erratics from the Cromer neighbourhood not yet found in the Suffolk deposit include shell-fragments (probably from the Corton Beds), wood and small black flints (probably from the Cromer Forest Bed or Till), and pink granophyre, several kinds of schist and pink acid gneiss (probably from the Corton Beds or Cromer Till). Various kinds of flint were found, but not the " basket-work " type which is so common in the Gipping Boulder Clay in Suffolk. A pink granite is similar to some in the Corton Beds. On the other hand, porphyrites of O.R.S. type (East Runton pit) are similar to those in the Gipping Boulder Clay. It would seem that this boulder clay near Cromer came from the north-west, picking up Lincolnshire Chalk, Cromer Forest Bed or Cromer Till, and some Corton Beds on the way.

The junction of the Chalky with the Chalky-Jurassic type of Lowestoft Boulder Clay seems to be abrupt, and the sections at Bawsey, east of King's Lynn, show the two types together. The occurrence of occasional fragments of marine shells in the pale part of the boulder clay at Bawsey makes it more likely that this belongs to the Lowestoft rather than the Gipping Stage, and similar sections have been seen along the line of junction near Scratby, north of Yarmouth. Violent contortions are typical of the zone of contact of the two parts of this ice-sheet.

Notes on Table I.—The rocks mentioned usually occurred as erratics, though some formed the matrix of the boulder clay in question, for instance, part of the soft chalk in the Gipping Boulder Clay. The various Jurassic clays which form the matrix of part of the Lowestoft Boulder Clay have not been included, as much work would have to be done on the foraminifera or the petrography, or both, in order to find out how much of the clay came from the Kimmeridgian, Oxfordian, and Lias respectively. Some of the more interesting or doubtful rocks have been sliced.

The shells mentioned from the Cromer district are, on the field evidence, almost certainly from the Corton Beds ; though the provenance of *Cardium edule* at Bawsey is not so definite. The wood fragments from the boulder clay near Cromer are associated with flints of Forest Bed type, but may have been derived through the Corton Beds or the Cromer Till, or both.

Among the Jurassic material, the Portlandian rocks are of special interest, and it is not easy to see at present where they have come

TABLE I

COMPARATIVE LIST OF CONTENTS OF THE CHALKY BOULDER CLAYS

	Lowestoft Boulder Clay				Gipping Boulder Clay		
	Claydon	Bawsey	Pakefield	Cromer	Claydon	Bolton's	Brundon
? Corton Beds							
Cardium edule		×		×			
Tellina balthica				×			
Cromer Forest Bed							
Fossil wood				×			
Blue-black flints				×			
Base of Crag							
Coprolites					×		
Tertiary							
London Clay Flints						×	
Cretaceous							
Grey tabular flint				×			
Fresh flint nodules	×	×	×	×	?	?	
Yellow flint	×	×	×	×	?	?	
Blue-and-white flint					×	?	×
Hard Chalk	×	×	×	×	×	×	×
Soft Chalk				?	×	×	?
Red Chalk	?				×	×	
Belemnites cf. *minimus*							×
Neocomian sandstone	×	×	×				
Jurassic							
Terebratula cf. *rosenkranzi* (Portlandian)		×					
Limestone with *Pavlovia* cf. *worthensis* (Portlandian)		×					
Septaria	×		×				
Kimmeridge Shale	×		×				
Ostrea delta (Lower Kim. Clay)			×		×		
Pachyteuthis abbreviata (Corallian)			×				
Ostrea dilatata (Upper Oxfordian)			×		×	×	
Oolite (prob. Lincolnshire)	×		×			×	
Pecten cf. *lens*		×					
Muddy limestone					×		
Lima hermanni (Lower Lias)			×				
Gryphaea incurva	?						
? Bunter							
Quartzites and sandstones	×	?	×		×		
Sandstone with pink spots	×						
Purple sandstone	×		×	×			
? Carboniferous							
Blue limestone	×		×		×		
Cf. Millstone Grit	×						
Basalt	×		×	×	×	×	
Old Red Sandstone							
Porphyrites				×	×	×	×
Red sandstone				×			
Age unknown							
Green mudstone						×	
Felspathic grit						×	×
Igneous							
Pink granite				×			
Pink granophyre				×			
Nordmarkite							×
Rhomb-porphyry						×	
Metamorphic							
Actinolite schist				×			
Various schists			×	×			
Pink gneiss				×			

from. Although not from boulder clay, it should be mentioned here that an erratic was found at Roydon containing *Rasenia* aff. *uralensis* (d'Orbigny), which Dr. Arkell dates as Lower Kimmeridgian. The provenance of this rock is equally obscure. It is interesting to compare these Jurassic fossils with the list published in the Memoir of the Geological Survey (Yarmouth Sheet, 1890, p. 53), where the occurrence of Lias material is recorded in the dark boulder clay at Ormsby St. Margaret, in addition to fossils from the higher Jurassic zones.

The quartzites and hard sandstones which appear to be from the Bunter are of some importance, as they have definitely appeared in Suffolk by Lowestoft Boulder Clay times.

The basalts have been compared with specimens kindly collected by Mr. W. E. Smith in Derbyshire, and are like, but not identical with, the Bonsall Sill. The slides from the erratics show that the augites are granular and sometimes idiomorphic, rather than ophitic. None of the basalt erratics examined so far are porphyritic like the coarse Scottish types. There are several places from which they might have come, and Derbyshire is among these.

The porphyrites are extremely weathered, and in some cases the minerals difficult to identify. The larger plagioclase phenocrysts (up to about 3 mm. long) are andesine or oligoclase, while the smaller laths are invariably oligoclase. Where the ferromagnesian minerals are identifiable, they vary considerably. Brown biotite was identified in one erratic (from Claydon), and green hornblende in another (from Bolton's pit). Some of those from the East Runton pit in the Cromer area are amygdaloidal. These porphyrites appear to be from the Scottish O.R.S. volcanic series. One erratic of dark red felspathic grit (not included in Table I) was found on the floor of the Claydon pit, which is interesting as it contained what appears to be green biotite among the grains of quartz and plagioclase, and is also remarkable as it includes a small pebble of granite with unstrained quartz, orthoclase, albite, and green biotite. This erratic, which was not *in situ* in either boulder clay, might be Old Red Sandstone.

The remaining felspathic grits differ from the above in having much more abundant quartz, with marked undulose extinction and filled with dusty inclusions. The erratic from Brundon also has brown biotite and a green mineral which is probably chlorite.

Some of the granite erratics from the boulder clay of the Cromer district are too soft to slice. One from East Runton pit, which was sliced, has abundant quartz and orthoclase, a little albite, much muscovite, and subordinate biotite. Haematite appears to be associated with the muscovite. It is not foliated. A pink granophyre from the same boulder clay has a little biotite interstitial to the intergrowth of quartz and orthoclase, with accessory magnetite and apatite. It differs

from a granophyre found at Brundon, which contains porphyritic albite.

The erratic of nordmarkite from Brundon is included here, because it was probably derived from the Gipping Boulder Clay at that place, although it was not found *in situ.* The subordinate quartz between the perthite phenocrysts is in optical continuity, and both arfvedsonite and aegirine are present. The erratic of rhomb-porphyry from Bolton's pit was within a few feet of an outcrop of Gipping Boulder Clay, and was probably from that deposit. The phenocrysts of anorthoclase are larger than is usual in erratics of this rock in East Anglia, up to 40 mm. long. A slide shows that well-formed crystals of apatite, up to 1 mm. long, were formed before the anorthoclase. The yellowish ferro-magnesian mineral is too altered for identification.

Most of the schists from the boulder clay near Cromer and the one from the Lowestoft Boulder Clay at Pakefield have not yet been worked out, but one from East Runton pit has a fine-grained mass of actinolite needles in quartz. An interesting schist erratic was found in the boulder clay overlying the Chillesford Crag in the pit east of Chillesford Church. It appears to be a quartz-felspar-muscovite schist, with subordinate biotite and albite. It has not been included in Table I, as it is uncertain which boulder clay this is.

Although not in a boulder clay, mention should be made of some erratics of pale amygdaloidal lava from the gravel underlying the Gipping Boulder Clay at Bramford. They are decomposed, but the porphyritic felspars seem to be about andesine or labradorite in composition, and one of the lavas has rounded clear quartz crystals up to 2 mm. in diameter. The cavities are filled with quartz and a green substance, and there are prominent apatite needles in the groundmass. They are presumably altered acid andesites or dacites. Solomon thought they might be derived from the Rhine province, but it seems also possible that they might be Scottish. They have not yet been found *in situ* in a boulder clay. Finally, the frost-shattered gravel at the top of the Hoxne section, of Gipping boulder clay age, has yielded a number of felspathic grits, one at least is schistose, and a fine-grained sandstone in which the quartz grains show strain-extinction, and this rock contains abundant tourmaline. Bunter Pebbles, basalt and Augen Gneiss have also been recorded by me from this gravel at Hoxne (in J. Reid Moir, 1935, p. 53).

Finally, belemnites from the Lowestoft Boulder Clay at Darmsden have been submitted for identification to Mr. L. Bairstow, and I am grateful to him for identifying one of these as *Neohibolites listeri*, from the Gault. A fossil from this formation at this locality is consistent with evidence for ice-direction already obtained at the nearby Claydon Cement Works.

Long-Distance Correlations

It has been shown that the Lowestoft Ice brought Jurassic material south-east from the neighbourhood of Lincoln and Grantham, and also much chalk south-east from the Lincolnshire Wolds, or perhaps more correctly from the present site of the Lincolnshire coast. It has also been shown that the Gipping Ice brought chalk from the Norfolk and Suffolk outcrops to the neighbourhood of Ipswich. If these conclusions are correct, it seems natural to suggest that a more westerly part of the Gipping Ice might have moved south into Fenland parallel with the southerly direction of this ice along the Chalk escarpment of Norfolk and Suffolk. Such ice would first cross the Chalk outcrop in Lincolnshire and carry chalk and flint on to the Jurassic outcrops in the Fenland. In my work on the March Gravels (D. F. W. Baden-Powell, 1934, pp. 212–215), it was shown that the glacial deposit which preceded the marine March Gravels consists of Chalky-Jurassic Boulder Clay. For many years I was unable to understand how this type of boulder clay could have been laid down in the Fens, especially as far south as Peterborough ; it was obvious that Harmer's ice-movement from the north-west (over Jurassic outcrops near Peterborough) could not possibly have brought chalk and flint to the southern Fens. But under the scheme suggested in the present paper, this problem is solved at once, and the Chalky Jurassic Boulder Clay of Fenland is seen to have been brought from the north by the same ice-sheet which brought so much chalk southward to Ipswich.

Again, it should be possible to use the erratics as confirmation of the ice-direction which has been deduced from the matrix of a boulder clay. The erratics from Fenland have not yet been worked out in detail, but hard chalk and grey tabular flint are certainly present in the boulder clay, with Kimmeridge Clay septaria, oolite, shelly limestone and white sandstone (probably both Jurassic), and the rarer erratics include felspathic grit and various schists. The Cretaceous erratics and some of the Jurassic fossils and erratics confirm ice-movement from the north, but more work is needed on this deposit to interpret the significance of some of the rarer rock-fragments. Some of them at least could be derived from Corton Beds or Cromer Till off the present Lincolnshire coast. The many erratics collected from the March Gravels are also awaiting detailed investigation. They seem to contain O.R.S. rocks which could be derived from any of the boulder clays off the Lincolnshire coast.

It is now possible to form some opinion about the three boulder clays reported by Paterson from Breckland. He has kindly shown me examples of these in the field, and I have no doubt whatever that his Upper Boulder Clay is the Gipping Boulder Clay of the classification suggested here. Paterson's Middle and Lower Boulder

Clays are not so easy to place. From what I have seen of the Middle Boulder Clay, its brown colour is like the weathered form of the Lowestoft Boulder Clay, but as far as I know few of the characteristic Lowestoft type of erratics have yet been collected from it. This would, of course, be in the correct stratigraphical position if it is of Lowestoft age. Paterson's Lower Boulder Clay is lightish blue in colour, and is probably the same age as part of the Cromer Till. Paterson (1937, p. 89) has mentioned that it contains Scottish quartz-dolerite, Yorkshire sandstone, and coal; until more work has been done on the Cromer Till it is not possible to be very definite, but some of this boulder clay seems to be involved in the dark-coloured Lowestoft Boulder Clay at Bawsey. Two observations must be made here about the Hunstanton Boulder Clay. Firstly, that deposit is quite separate from the Gipping Boulder Clay, the two being separated by the March Gravel mild period. Secondly, the Hunstanton Boulder Clay contains a different suite of erratics (so far as they are known) from either the Gipping Boulder Clay or the Upper Boulder Clay of Paterson's classification. The conclusion from these facts is that the Hunstanton Boulder Clay is later than Paterson's Upper Boulder Clay.

General Correlation with the East Midlands.—The ice-directions for the Lowestoft and Gipping stages, which have been worked out in the present paper, solve certain problems of East Anglian and Fenland geology. But these ice-directions are also in remarkable agreement with results reported from a wide area in the Eastern Midlands. As far afield as the counties of Derby and Nottingham, a glacial sequence was described by Deeley (1886, pp. 439–440 and 454–462) which proved that Pennine Ice had emerged south-eastward from the Southern Pennines at a date prior to the invasion of the Trent Valley by Chalky Boulder Clay from the north-east. Harmer (1928, pp. 113, 132-146) mentioned both Pennine and Chalky Drift in the East Midlands, and considered that the Pennine Drift might be the older of the two, and a similar sequence is indicated in the relevant Memoirs of the Geological Survey. More recently, Hollingworth and Taylor (1946, pp. 230–5) have shown an almost identical sequence near Kettering, with a lower boulder clay with Bunter and Jurassic material, but no chalk or flint, succeeded by later drift with chalk and flint.

Further, observations of my own (so far unpublished) between Buckingham and Leicester confirm the fact that the latest ice-sheet in that area has crossed Cretaceous and Jurassic outcrops, presumably from the north-east. All these facts suggest strongly that the Pennine Ice which moved from north-west to south-east from Derby to the valley of the Great Ouse is the upstream part of the ice-sheet which deposited the Lowestoft Boulder Clay in East Anglia, and that the later Chalky Boulder Clay of the East Midlands is part of the Gipping

Ice-sheet. This correlation has, in effect, been made already by Boswell (1932, Table facing p. 88) and by K. Harrison (1937, pp. 242, 243, and 249), who also correlated the Upper Chalky Drift of East Anglia with Deeley's Chalky Boulder Clay from the north-east. These relations between East Anglia, Fenland, and the East Midlands generally are summarized here in Table II.

TABLE II

CORRELATION OF THE BOULDER CLAYS

East Suffolk	Cromer (Solomon)	Breckland (Paterson)	Fenland	East Midlands (Deeley, etc.)
—	Hunstanton	—	Hunstanton	Late Pennine
Gipping	Little Eastern	Upper	Chalky-Jurassic	Great Chalky
Lowestoft	Great Eastern	Middle	—	Middle Pennine
Cromer Tills	North Sea Drift	Lower	—	Early Pennine

In conclusion, it may be said that this examination of the chalky boulder clays of East Anglia has found Harmer's theory of a single ice-sheet to be unsatisfactory. The facts are better explained by the hypothesis that there have been two separate " chalky boulder clay " ice-sheets which differed somewhat in their direction of movement, as shown in Text-figs. 1 and 2 (compare maps by MacClintock, 1933, p. 1051). The lines of flow have been reconstructed as accurately as possible, and the types of deposits laid down are also noted on the sketch-maps.

Text-fig. 1 shows the ice-movement at the stage when Chalky-Jurassic boulder clay was being formed at Lowestoft and Ipswich, with contemporaneous Chalky boulder clay at Cromer. The relation of these deposits to the Chalk escarpments is evident. It will be noticed that the two main ice-sheets are convergent in Norfolk, a fact which may partly explain the famous Cromer contortions.

Text-fig. 2 illustrates the later Gipping stage, when Chalky Boulder Clay was formed at Ipswich, and Chalky-Jurassic type of drift in the Fenland. Correlation with Solomon's Little Eastern on the Cromer coast shows that this ice failed to pass over the Cromer Ridge, which had been formed during the earlier Lowestoft stage. This explains the ice-free area north-east of Ipswich, where outwash gravels replace this boulder clay. It will be observed that there is a slight tendency for this ice-sheet to fan out on reaching the Fenland, but much less so than in the case of Harmer's " Great Eastern Glacier ".

If the correlations depicted here are correct, we have a simple solution of the problem discussed by Zeuner (1945, pp. 108–110). On the data available at the time, Zeuner saw that it was difficult to reconcile Solomon's idea that the Little Eastern Drift was restricted to northern Norfolk with the description of Upper Chalky Drift in the Ipswich district. Zeuner considered two possibilities; either the Little Eastern of Norfolk was a retreat stage of the Upper Chalky Drift of Ipswich, or the upper deposit at Ipswich would have to be correlated with the Chalky-Jurassic Boulder Clay at Corton and the Chalky Boulder Clay at Cromer. The present work on ice-directions seems to rule out the second alternative as impossible, and the first alternative becomes unnecessary, if Solomon's Little Eastern Drift can be correlated direct with the Ipswich Boulder Clay as shown on Text-fig. 2 of the present paper.

Finally, the evidence of the marine zônes and of the implements in East Anglia are in agreement with the glacial sequence which is demonstrated in the present paper. The marine fauna of the Corton Beds is of an earlier type than that of the March Gravels, and the glacial sequence worked out independently puts the Corton Beds in an early, and the March Gravels in a late, interglacial stage. The position of the implements is too large a question to deal with here in detail, but it can be stated briefly that if the glacial sequence is worked out first without reference to the implements, the archæological sequence shows that the Abbevillian is at least partly earlier than the Cromer Tills; Early Clactonian is the main type found between the Cromer Till and the Lowestoft Boulder Clay; between the latter and the Gipping Boulder Clay the main implements are Acheulian, advanced Clactonian, and Early Levallois; whereas late Acheulian (? derived), Late Levallois and types resembling Aurignacian are found between the Gipping and the Hunstanton Boulder Clays, or as derived specimens in the Hunstanton Boulder Clay. The glacial sequence is therefore parallelled by the development from more primitive to more advanced types of implements.

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Some Puzzling Features of Alpine and West Indian Metamorphic Rocks

By C. T. Trechmann

IT should by now be fairly well realized that the West Indian islands are not a subsiding mountain range, but represent rather an Alpine or Pyrenean area in process of emerging from the sea. In the West Indies we witness something of the condition of metamorphism of the rocks as they came up. Comparison of the metasomatism of the formations in the two widely separated areas of the Alps and Antilles may provide some evidence as to how the processes operated and what sort of forces raised them up.

Blocks in the Flysch of the Habkerenthal

The Flysch is a facies formation, well seen along the north side of the Alps, the Carpathians, at the west end of the Pyrenees, and elsewhere. A formation of early Eocene age of similar aspect, the Carbonaceous Shale, occurs in Jamaica. The Flysch seems to be destined, because of some reasons connected with its special conditions of deposition, depth, and peculiar composition, to come up again and take a prominent part in mountain uplifts.

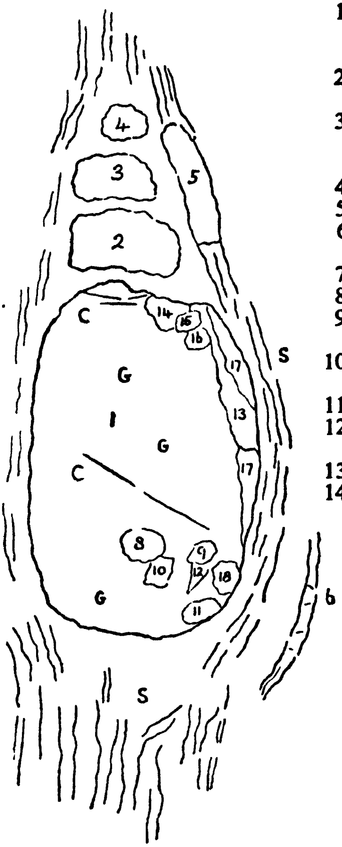
The so-called " exotic " blocks in the Swiss Flysch are said to extend from the Lake of Thun eastwards to the Rhine. " Man kann alle Uebergange von Conglomeratanhäufungen zu ' exotischen ' Blöcken und eigentlichen Klippen verfolgen " (3, p. 123).

The Habkerenthal near Interlaken is famous for its blocks. Most of them lie loose in the stream, having apparently been washed out of the shale, and being too massive to be carried away, have accumulated there. I paid more attention, however, to the masses that are to be seen *in situ* in the Flysch on the roadside about half-way between Interlaken and Habkeren. One of these is specially interesting because it seems to be the block seen by Murchison 100 years ago. This block, or one very like it, has been illustrated in many books since his time but its size seems to have been exaggerated. E. B. Bailey (1, p. 73) reproduces it as a " 10 foot exotic block of granite ". It has also been figured by Baltzer, Heim, Schmidt, and others.

Murchison (4, p. 211) writes: " The largest of the concretions visible in the course is an oblate spheroid about 4 feet long by 3 feet wide," and he continues (p. 212), " But whether produced in the same manner as the so-called volcanic or plutonic grits of other regions, by contemporaneous segregation of the igneously-formed particles in the bottom of a turbid sea, or by subsequent partial alteration of the strata through the action of heat and gases, or by

transport from other rocks, it is clear that these small developments of granitic matter are contemporaneous with the Flysch." These blocks are now usually referred to as granite "exotics" or "erratics".

I made a sketch of this block, which I will call Murchison's block, and refer to it as block "M" (Text-fig. 1). It is about 4 feet high,



1. Main block composed mostly of coarse grey granite, the exposed face is a fractured surface.
2. Dislocated portion, glauconitic nummulitic grit.
3. Higher dislocated part, fine-grained comminuted welded grit, unfossiliferous, or with broken up foraminifera.
4. Hardened Flysch.
5. Mass of bedded hardened Flysch.
6. Bedded gritty calcareous Flysch, with a few foraminifera.
7. Hard bedded fine gritty Flysch.
8. Mass or nodule of brown limestone.
9. Nodule of brown unfossiliferous limestone.
10. Quadrangular piece of coarse granitic pegmatite.
11. Coarse-grained whitish pegmatite.
12. Limestone and grit with nummulites and other foraminifera.
13. Coarse whitish pegmatite.
14. Mass of whitish pegmatite.
15. Pebble of brown limestone.
16. Quartz and greenstone disposed in bands or lenses.
17. Glauconitic nummulitic grit forming a sort of outer coating welded on to the block.
18. Glauconitic nummulitic grit welded closely to the granite.

GG. Granite of the block. CC cracks or fissures, those at the top are gaping and filled with calcite.

SS. Shaly contorted Flysch, moulded around the block

TEXT-FIG. 1.—Sketch of granite and composite block "M" in the Flysch of the Habkerenthal near Interlaken, Switzerland. Height of the block and its two upper detached pieces, about 5 feet.

rounded below but narrowing upwards, where two or possibly three pieces, that evidently once formed part of it, have been detached and drawn some distance upwards. The enclosing Flysch dips almost vertically and the shale and its harder bands seem to have been pressed or moulded against the sides of the block. The shale is contorted and disturbed and some patches of it are almost as slaty as the well-known fish bed at Matt in Canton Glarus. The harder bands near

the block consist of calcareous gritty shale containing a few nummulites and algal remains.

As this block is evidently a " show specimen " I took only a few small chips off it ; among them are the following :—

(1) Coarse grained grey granite from near the lower part of the main mass. It is composed of quartz, clear felspars, and large biotites ; a very fresh rock which makes up the greater part of the larger block.

(2) Whitish pegmatite with quartz, cloudy felspar, and little biotite. This material occurs in patches and in places it has a rounded apparently waterworn outer surface. A piece of it in the lower part of the main block has quite a distinct outline, and looks like a pebble that has become incorporated in the granite.

(3) Coarse pegmatite banded with quartz and greenstone, that merges into a sort of hornblende amphibolite.

(4) Quartz and felspar grit with remnants of brown limestone, some of it silicified, with glauconite grains and patches of glauconite. Some of the felspar and biotite crystals in it seem to be of secondary growth, and the quartz and felspar grains are sometimes stretched and fractured and the parts rejoined by calcite. In this grit there are numerous nummulites and other foraminifera, some of them replaced by or filled with glauconite. This nummulitic grit appears mostly near the right hand outer surface of the block, but patches of it occur also well inside the granite mass. It is so closely welded or attached to the granite and pegmatite that when one tries to chisel a piece off, the plutonic rock often comes away with it. The nummulites in it are often fragmentary or eroded, or rather distorted.

(5) A small pebble of brown limestone without fossils, but with some of the glauconitic grit welded to its surface. It has the appearance of a waterworn pebble that has by some means become incorporated in the granite mass.

(6) A chip from the lower of the two upwardly detached pieces. It is a coarse quartz and felspar glauconitic grit crowded with nummulites, partly glauconitized. Some parts of it seem to be compressed and the nummulites drawn out or distorted as if it had been to some degree plastic.

(7) A piece of the upper of the two detached portions. A fine grained very hard welded glauconitic grit veined with calcite. No foraminifera are to be seen. It looks as if the grit had been broken up into much finer grains, the particles more closely welded and the nummulites if they existed, obliterated.

The foraminifera in this block have been kindly identified by Dr. C. D. Ovey as *Nummulites* sp., *Discocyclina papyracea*, Boubée, together with algae.

The upper surface of the main block when looked at from above, seems to have been cleaved or fissured for some distance downwards, the cracks being rejoined with calcite. The part of it facing the observer is a broken surface and shows the structure probably 3 inches inwards from its original surface.

This block is a very curious composite affair. The smooth outer surface seen here and there on the granite, pegmatite, and greenstone parts of it seem to show that some of the masses that have coalesced to form it were originally water-worn boulders and pebbles. The presence of limestone pebbles in and among the granite portion as well as forming part of the outside, some of them silicified or steatitized, also indicate its composite nature. It is not easy to understand why the Nummulite and *Discocyclina* grit should have accumulated round or against a granitic block, or among a cluster of plutonic pebbles. Why should the grit here have become so strongly glauconitic, and how did it become welded so strongly against and among the masses ? The lower of the two upwardly detached parts seems to consist of glauconitic grit full of *Nummulites*, while the higher part that once formed part of the same mass is made of much finer grained grit, also glauconitic but devoid of *Nummulites*.

Murchison was evidently right in saying that the block is a growth formed *in situ*. There appears to have been a pocket of pebbles, including a mass of granite, pieces of pegmatite and limestone, with grit full of foraminifera. This collection or cluster of material became welded together into the boulder as we now see it.

The mass once presumably lay with its longer axis horizontal on the sea bed, the shale was up-ended and the metasomatic or welding process continued as the higher part became squeezed and detached.

The process seems to have acted especially among the pockets of loose fragments. These masses occur among the Flysch that is in the contorted and disturbed condition that is known as " Wild Flysch ", but the enclosing Flysch is not metamorphosed, nor is it especially glauconitic.

Some 100 yards to the north, in the bed of the stream, the Flysch is more normal and is not broken up or disturbed. The beds dip steeply but are not quite vertical. Mudstones and impure limestones alternate with shales, and some of the more massive beds are traversed by calcite veins. Fossils in the shales and limestones include *Nummulites*, *Heterostegina*, algae, and small corals, but they are not impregnated with glauconite like the nummulites associated with the block.

Professor A. Heim (2, p. 358) states that the Wildflysch at this locality " lies thrust and faulted in a syncline of the Upper Eocene Stadschiefer of the Wildhorn Decke ". But the foraminifera adjacent to the block are quite similar to those in the undisturbed Flysch in

the stream. Also if there had been lateral nappe thrusting how does it happen that the blocks lie with their longer axes upright and the pinched upper parts drawn off upwards? It seems to me that the broken and disturbed character of the Wildflysch is the result of some process connected with conditions of deposition and subsequent uplift, rather than with mechanical thrusting.

About 12 miles to the south-west, on the south side of the Lake of Thun, is the great ridge of Wildflysch that culminates in the "pyramid" of the Niesen. A few yards down the road to Interlaken there are two more blocks in the steeply dipping Flysch, above a parapet wall. One is a rather angular mass of very hard dark greenish-grey rock. When one examines the surface where it adjoins the shale or looks at a broken surface it is seen to be a quartz felspar pebbly grit that has become welded till it has almost the appearance of a plutonic rock. Pieces or wisps of brown limestone, now mostly silicified, occur in it, together with clusters of biotite and chlorite that seem to be of secondary growth, while specks and grains of glauconite occur in what has been the matrix. Some of the bits of limestone in it are brecciated but show no fossils. When fractured, the rock tends to break around the original surfaces of the small pebbles, some of which are dioritic in character.

The other is about the same size as Murchison's block "M", but is less interesting as no nummulitic grit seems to be associated with it. Its base is rounded below, the top narrows or is pinched out and drawn upwards as detached fragments. It is composed of rock also of plutonic appearance, but is lighter coloured and mottled. It is obviously a welded and coalesced coarse grit or conglomerate with pieces or streaks of silicified brown material that has evidently been limestone, but which has been mostly removed. The pebbles that coalesced to form this block seem to have been larger than those in the near-by smaller mass, some of them have consisted of a greenish quartz and hornblende rock. The rough and irregular outer surface where it joins the enclosing Flysch is coloured dark green and is sprinkled with glauconite grains. In this block the pebbles are more intimately coalesced than in the smaller mass and the rock breaks through the original pebbles and not around them.

Some distance up the road towards Habkeren the Flysch is more contorted and encloses many smaller blocks and lumps. The road was here being widened and a good assortment could be examined. They are here all apparently geodes or concretions and not water-worn or exotic blocks. One lump I broke open was about 7 inches in diameter. The exterior is dark green in colour, the surface where it joins the shale quite rough and irregular. The outer part extending to about an inch inwards consists of comminuted welded grit in which

the end of a belemnite is embedded. Its central line and radial crystalline structure is perfectly preserved, it is not crushed and is quite calcareous. The matrix is devoid of calcite except for a very fine vein running through it. Some of the quartz grains of the gritty part have become " ghosts " and shade gradually into the matrix. The outer part of this lump passes inwards with no visible line of separation into a coarsely crystalline material having the appearance of granite. Here and there, both in the grit and in the granitic part, are a few twisted fragments of brown siliceous or steatitic material that has evidently been limestone. One piece is internally slickensided on a small scale, apparently the result of contraction following on the removal of the calcite.

We seem to have here a case of a calcareous gritty rock from which the calcite has been removed leaving only the " indigestible " belemnite.

Towards the centre, the piece has been converted into a material that is coarsely crystalline like a plutonic rock. Biotite crystals 2 or 3 mm. in size occur in the interior part and also in the welded grit adjacent to it, and seem to be of secondary origin. They are similar to the biotites in the granite of the main part of block " M ". The outer part is very fine-grained glauconitic grit like that in the higher drawn-up piece of block " M ".

Belemnites, probably because they are composed of pure crystalline calcite, seem to survive the processes of metamorphism. In the Alpine mica-schists they retain their original circular cross section, though they are often stretched and fractured and the spaces filled with calcite. Our fragment is the end of a guard apparently of *Belemnitella*. Belemnites are recorded from several localities in the Flysch, whence it has been concluded that part of the Flysch is Cretaceous or Jurassic in age. This lump, however, seems to have resulted from metasomatism of a piece or cluster of pieces of derived material.[1]

Another lump about the same size is a fine-grained dark green very hard welded grit with streaks of coarser felspathic and glauconitic material. There are specks of brown limestone in the coarse veins which contain no fossils. The outside of this lump is irregular and dark green with glauconite, but one side of it is shaly and slickensided where it has joined the Flysch.

Another lump is a mass of hard grey limestone almost made up of algal structures with a few nummulites. The surface where it adjoined the enclosing shale is quite irregular and has blebs of secondary opaline silica that have grown on it, and it is sprinkled with glauconite grains. Fair sized biotite crystals occur here and there in the limestone

[1] It is in no sense a derived piece from the contact of a granite and sedimentary rock, but a pocket or geode whose constituents have been " congested " in the inside of the lump to a coarsely crystalline condition.

and seem to be of later growth and not detrital. This lump is evidently a concretion or contemporary accumulation in the shale.

There are many such limestone concretions in the shale here and outwardly they do not differ in appearance from those of welded grit or granitic rock ; it is only when one breaks them that one ascertains their nature. Only the larger blocks that stand upright seem to be rounded below and attenuated and fractured and drawn off upwards. Their condition is evidently in some way connected with the forces that uplifted the Alpine region. Mountain uplift seems to be associated with chemical and metamorphic changes in the rock as well as with mechanical forces.

I saw no blocks *in situ* in the Flysch of the Habkerenthal that could be regarded as water-worn " exotics ". Those that lie loose in the river are rounded and have had their outer crusts removed. Most of them are fresh granite with conspicuous pink felspar crystals, not unlike our Shap granite, but in nature quite like the grey granite that forms most of block " M ". Another mass that was being broken up on the roadside was a welded glauconitic grit but without fossils.

Some of these loose blocks are so large that they have been taken to be glacial erratics, but it is stated that no granite occurrence is known from which these erratics or exotics might have been derived.

Comparison of Alpine and Antillean Metamorphic Features

The formations that make up the core of Jamaica, rudist limestones and shales and Eocene beds, resemble in many ways those of parts of the Alpine, Provençal, and Pyrenean regions. They have been raised to 7,000 feet and partially metamorphosed during the process. The island is surrounded by sea as deep as 21,000 feet and there are no old masses to be seen that might have caused any thrusting.

I was surprised, however, in the Alps, to find metamorphic features so similar to those I had seen and puzzled over in Jamaica and Trinidad. Block " M " in the Flysch is partly cleft downwards and the cracks filled with calcite ; while some grains in the welded grit are stretched and cracked and the pieces rejoined by calcite. In the Blue Mountain conglomerates of some parts of Jamaica the rounded water-worn pebbles are partly shattered, the fragments drawn off and rejoined by calcite derived from adjacent rudist limestone pebbles. The drawn off parts form sort of flat tails attached to the pebbles. The shale enclosing these lenses of fragmented pebbles is not tectonically disturbed (5, p. 163, pl. v, figs. 1, 2, 7, and 8). The small mass in the Flysch that contains the piece of belemnite in welded grit which merges into granitic material, recalls a feature that is seen in Jamaica. Fragmented conglomerates, a further stage in the shattering

of the pebbles, become mushed and impregnated with chlorite and glauconite, the calcite has largely been removed and the mass passes into a rock having the appearance of granodiorite. Bits of silicified limestone full of foraminifera remain here and there and show that limestone pebbles once existed in the conglomerate and have been removed by some underground process.

A similar withdrawal of limestone has apparently occurred in several of the blocks in the Flysch of the Habkerenthal, as is shown by the wisps of silicified limestone that remain. In Jamaica the uplift seems to have occurred together with metasomatic recrystallization. The Yellow Limestone, of lower or middle Eocene age, in places is full of irregular pieces of glauconite ; foraminifera in it are impregnated with glauconite, while corals in it are silicified as well as slightly glauconitized. The nummulitic grit associated with the composite welded block is also full of glauconite and the foraminifera are largely replaced by it. How have the pockets of grit that form the blocks of the Habkerenthal become glauconitic, while the enclosing shale has not ?

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The Direction of Origin of the Kalahari Sand of Southern Rhodesia

By GEOFFREY BOND (formerly Keeper of Geology, National Museum of Southern Rhodesia)

THE Kalahari Sand formation extends over a large part of the territory of Southern Rhodesia, and it has been estimated that it covers 12 per cent of the surface of the Colony.

Extensive as these sands are in this territory, they are only the eastern fringes of a spread of sand which covers an enormous area of Southern Africa, being probably the most extensive single geological formation in the sub-continent.

In Southern Rhodesia the sands reach a maximum thickness of a little over 200 feet. They are very seldom exposed in good sections. They are often covered with thick bush, and generally form great stretches of flat, forest country, without surface water, and although their distribution is well known, little detailed information has been published about them.

The determination of their age, or ages, has proved to be a difficult problem, and they have been at different times, considered to be of various ages ranging from late Cretaceous to Middle Pleistocene. The valleys of the present river system cut through them to expose the older formations, and yet at two localities, the Victoria Falls on the Zambesi, and at Sawmills on the Umguza River, older Palaeolithic implements appear to be overlain by undisturbed Kalahari Sand. The tendency at the present moment is, therefore, to consider them to be Middle Pleistocene, at least in part. Probably they have moved at various times, whenever the climate became sufficiently arid. Even to-day a certain amount of drifting takes place at the end of the dry season around the shrunken remnants of pans and on other bare spaces.

The best exposure of the sands is in the railway cutting near the Victoria Falls in the Zambesi Valley. This section was described by Maufe (1939) and exposes the following succession :—

Red Kalahari Sand	30 feet (top not seen).
Carstone rubble bed (with Sangoan implements) .	0–4 feet.
Red Sand (non-sequence)	0–10 feet.
Pipe Sandstone (non-sequence)	0–10 feet.
Chalcedony (unconformity)	0–5 feet.
Basalts of Karroo System.	(Base not seen.)

The thicknesses are variable, and only the basal part of the Kalahari Sand is present in this section. The generalized distribution of the Sands is shown in Text-fig. 1, all the outcrops being on the north-western side of the main watershed which runs diagonally N.E.–S.W. across the territory.

It has been well established by previous workers that the main bulk of the Kalahari Sand accumulated under dry conditions and was transported by wind action. It is likely that the conditions were not completely arid. The sands contain a large proportion of perfectly rounded millet-seed grains, but about 50 per cent of the bulk passes a 90 IMM sieve, and there is no evidence of dune bedding, or any other structure, except a vague horizontal layering in the few exposures available for study. The sands are quite unconsolidated, but stand well in cuttings, owing to their high content of fines. The dominant colour is a bright red, due to a pellicle of iron oxide coating the quartz grains. Particularly in the forest-covered areas, the surface sand is often bleached to pale yellow or grey, but the diggings of ant-bears, often reaching a depth of several feet, show that the red colour is present in depth. It seems likely that the sands indicate a rainfall regime that was sufficient to support grass growth in a short wet season (summer), but that drifting took place in the long dry season (winter). The red oxide would accumulate by capillary rise under these conditions of contrasted seasons, and it is probable that the total annual rainfall may have been as high as 10 to 15 inches per annum. Nevertheless, such a great spread of semi-desert sand indicates a considerable extension of conditions rather like those in parts of the present Kalahari desert, over a huge tract of Africa, probably in response to world-wide changes of climate. Macgregor (1947) has estimated the volume of sand in Southern Rhodesia as 20,000 cu. miles and has touched upon the origin and wind direction which brought this mass into the territory. He writes : " The source of this volume of blown sand . . . can only have been the sea floor exposed by a recession of the waters caused by the uplift of the continent and later by the accumulation of ice at the polar regions during the Pleistocene Ice Age. It seems probable . . . that the Rhodesian Kalahari Sand was blown in by trade winds from the East, and was deposited over hill and dale as large wind-way dunes or ' Siefs '." It is hoped to deal in a subsequent paper with the general climatic significance of the Kalahari Sand, and the implied correlation of so widespread a desert phase of climate in the Southern Hemisphere with glacial phases in the polar regions. The present paper will be confined to an examination of the evidence which the heavy minerals of the sands provide in determining the direction of drifting, which in the absence of dune-bedding is the only weapon available in such a study.

Treatment of Samples

The method of separation of the heavy residues followed more or less orthodox lines. The unconsolidated sands were first passed, dry, through a 30 IMM sieve. The fraction passed by the sieve was panned to a reasonable bulk, and passed through bromoform. The heavy faction was washed, dried, and separated with a permanent magnet. Permanent mounts were made of the non-magnetic fractions only. Great care was exercised throughout to ensure uniformity of treatment, as considerable variations can be introduced by slight changes in handling. A few light fractions were mounted for the examination of the grains. The heavy fraction seldom exceeded 0·5 per cent of the sample and the magnetic fraction was generally about 25 per cent of the total heavies. Pipe Sandstone and Karroo samples, which were separated for comparative purposes, were first crushed as gently as possible, and then subjected to identical treatment. Very few freshly broken grains have been found in the residues.

The Heavy Minerals

The heavy mineral assemblage is a restricted one, as befits an aeolian sand. All the residues contain zircon, tourmaline, rutile, staurolite, and kyanite, and small amounts of epidote, brookite, apatite, and sphene occur in a few of the samples. Garnet is absent from all separations of the main Kalahari Sand, but is present in the red sand below the Carstone rubble bed at the Victoria Falls, and in separations from the underlying Pipe Sandstone. It is universally present in separations from the Forest Sandstone, of Karroo (Upper Triassic) age.

Zircon is represented by all the typical varieties ; waterclear, dusky, yellow, and purple, zoned and unzoned, all being well distributed. They are usually of small size and are nearly all very well rounded.

Tourmalines are of various colours, including almost colourless, blue-green, brown, and yellow. The rutiles show two distinct varieties, pale yellow being much rarer than the foxy red.

The brookites are rare ; all are pale yellow and longitudinally striated. Sphene is also rare, and is of the cinnamon-brown colour so common in the granite of this country. There is a complete absence of platy minerals, and it has not been possible to find micas even by examining the washings from pannings.

The Light Fractions

The light fractions consist almost entirely of quartz. The larger grains are beautifully rounded, but pass down into angular chips with

decrease in grain size. Fresh microcline occurs as rare grains, and a little fresh oligoclase is also present.

An analysis of the quartz grains based on the types of inclusions, shows that regular and irregular types are equally abundant, acicular types rare, and grains showing no inclusions practically absent. This suggests that about equal amounts were derived from granitic and metamorphic rocks. Sillimanite needles, rutile, and brown tourmalines are common as inclusions. Grains showing undulose extinction occur frequently.

Magnetic Fraction

This consists largely of magnetite, with some haematite, and a little pyrrhotite. The grains are well rounded.

The Provenance of Certain Minerals in the Kalahari Sand

In seeking the direction of origin of the Kalahari Sand the method of observing the direction of dune-bedding is not available. There remains the possibility of determining the direction in which the percentage frequency of particular species, or their grain-size and degree of rounding, show progressive changes. The most significant minerals present in the separations proved to be staurolite and, to a lesser extent, kyanite. All the other minerals are stable and widely distributed species which in this case give no clue to origin. Staurolite and kyanite are, however, comparatively soft minerals which are easily reduced in size under conditions of wind transport, and are of restricted primary occurrence in this part of Africa.

Frequency counts of these two minerals show that their percentage undergoes a general decrease in a southerly direction. Grain-size measurement of staurolite, which is present in all the residues, brings out the fact that the largest grains in separations from the northern part of the main outcrop of Kalahari Sand are invariably of this species, but that in the extreme south, staurolite grains are at least as small as the average for zircons, and that the degree of rounding also shows a marked improvement in the same direction.

Since the size of the largest single grain in a separation is a rather unreliable factor, a number of large grains, generally about 10, were measured and the figures averaged to give an " average maximum grain size " for staurolite.

These figures showed a very obvious decrease in a southerly direction. The results are shown, together with the percentage of staurolite, in Table I, and are presented graphically in Text-fig. 2. In this graph the average maximum grain-size for staurolite is plotted against the distance south of the district around Miami (see Text-fig. 1), which is on the southern margin of the Lomagundi Mica fields.

TABLE I.

Locality.	*Max. Diameter of Largest Grain.*	*Av. Max. Diameter of Largest Grains (10 ±).*	*% of Staurolite.*
Gokwe a. .	0·675 mm.	0·53 mm.	15
" b.	0·72 "	0·56 "	
" c. .	0·70 "	0·54 "	
" d.	0·70 "	0·53 "	
" e. .	0·50 "	0·43 "	
Victoria Falls a.	0·38 "	0·34 "	8
" " b.	0·53 "	0·41 "	
Dett a.	0·47 "	0·42 "	13
" b.	0·53 "	0·41 "	11
Matetsi	0·33 "	0·31 "	
Gwaai Bridge	0·41 "	0·38 "	10
Malindi	0·59 "	0·36 "	7
Teak Forest	0·34 "	0·33 "	13
Sawmills .	0·36 "	0·29 "	8
Umguzaan	0·31 "	0·21 "	
Bulawayo a.	0·19 "	0·15 "	1
" b.	0·19 "	0·15 "	5
Beatrice a.	0·25 "	0·22 "	2
" b.	0·36 "	0·31 "	4
Umvuma .	0·36 "	0·31 "	2

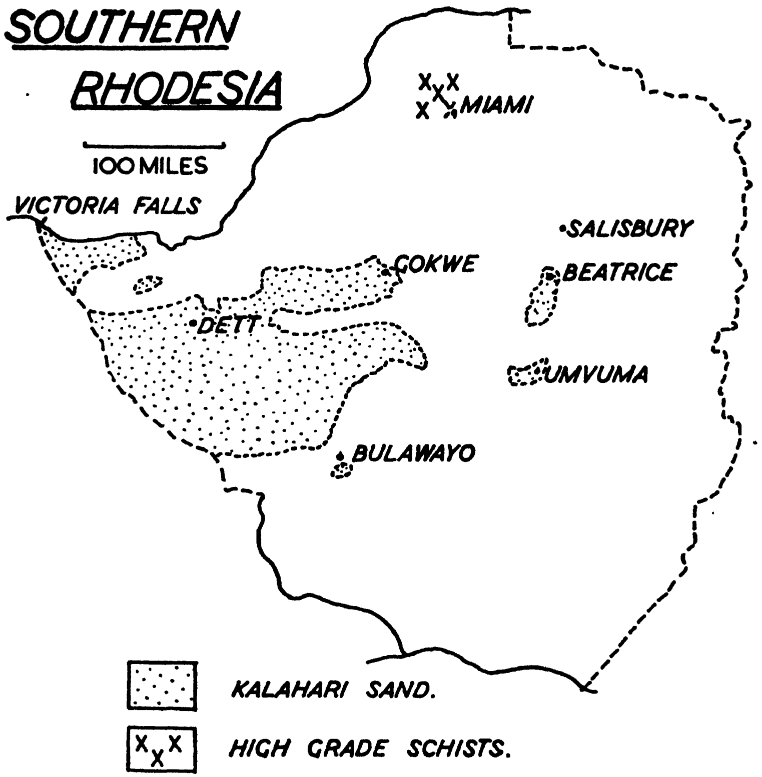
This small region is known to contain high grade metamorphic derivatives of the Lomagundi System, and Maufe (1920) has described staurolite-kyanite-schist in this area, with staurolite crystals up to 2 inches in length. Similar rocks are also known to the north-west of this in Northern Rhodesia. Such schists are also found in Portuguese East Africa, but they lie at a considerably greater distance, and material from this source would have had to be blown across the mountainous eastern border of Southern Rhodesia before reaching the plateau country.

In constructing the graph it was assumed that the Miami Schists were the most likely source of the staurolite in the Kalahari Sands, and distances were measured from them for all samples.

The scatter of points so obtained shows that all the samples taken from the main outcrop of the Sands, which is a little west of south from Miami, lie reasonably close to a smooth curve, and are therefore likely to have been derived from a single source region, but that certain groups of samples are well off this line. Thus, the samples from the Victoria Falls area lie well off the curve, and are unlikely to have been derived from the same region. If, on the other hand, they are re-plotted as distances from the known area of high grade schists in Northern Rhodesia, a little east of north from the Victoria Falls, they fall nicely on the curve, and hence the conditions of transport and deposition must closely have resembled those of the main area.

The samples from near Beatrice are also off the curve. This locality

lies south of Miami (see Text-fig. 2), but well to the east also. If the main direction of drift was almost due south, the samples from Beatrice must have either received their staurolite from another source at a greater distance, or by a round about distribution of material

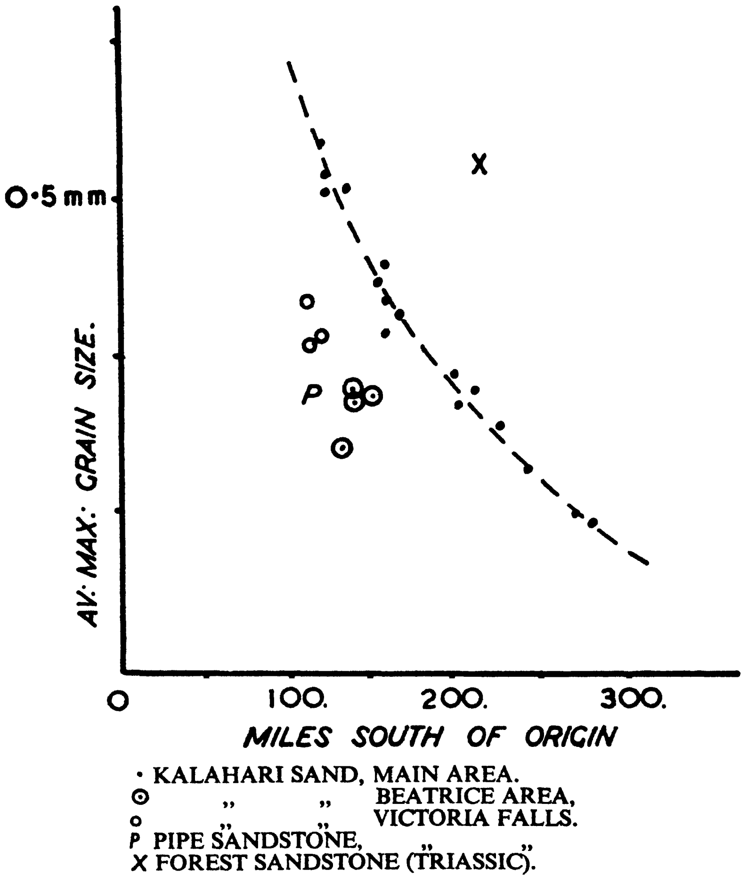


TEXT-FIG. 1.—Outline Map of Southern Rhodesia showing the areas covered by Kalahari Sands and the small area of high grade schists containing staurolite.

from Lomagundi schists which resulted in a longer period of transport, and resulting reduction in grain size.

The greatest contrast in grain size is between the samples from Gokwe and Bulawayo, which lie on a line due south of Miami. The evidence from this single mineral species, therefore, is interpreted as indicating that it was distributed in the main outcrop of the Kalahari Sand from a source near Miami, and was drifted by winds which were dominantly from the north, with only a very small easterly element, and probably with a slight anticlockwise rotation. The extremely close agreement of the points with the curve, and the known

occurrence of a source of this mineral, leave little room for doubt that this was the direction of travel. The curve itself is of the form which would be expected from theoretical considerations, the volume of a grain being reduced by attrition in inverse proportion to the



TEXT-FIG. 2.—Graph of average maximum size of staurolite grains against distance from their supposed source of origin.

distance travelled. The close approximation to a regular curve renders it likely that drifting was only possible at one season of the year, since the regular distribution would have been upset by the change of wind direction inevitable with the change of the seasons. That drifting only took place in winter was suggested above, when the conditions of deposition were under discussion.

Earlier suggestions as to the parent rocks of the Kalahari Sands in Southern Rhodesia have included the disintegration and redistribution of the underlying Pipe Sandstone, and also the breakdown of Karroo sediments such as the Forest Sandstone, as well as Macgregor's suggestion quoted above, that the sands were brought from the sea shore.

With the object of testing these various suggestions, separations were made from a number of samples of Karroo sediments and Pipe Sandstones. As a result, it is not possible to rule them out entirely as contributory sources, but the grain size of staurolite is consistently smaller in the Karroo Sandstones, particularly in those of desert origin, such as the Forest Sandstone and the overlying Nyamandhlovu series. These cannot, therefore, have contributed this mineral in significant amounts to the overlying Kalahari formations, and it must have been derived at first hand from staurolite-bearing schists. It is quite likely that the Karroo rocks derived their staurolite from the same area, but conditions must have been rather different since the grain sizes do not fit the curve which satisfies the Kalahari samples. The Pipe Sandstone is not a likely source for the Kalahari Sands although staurolite falls into the size range of these sands. However, the Pipe Sandstones contain abundant large grains of pink garnet, as noted by Maufe (1939), with some monazite and apatite, minerals which are absent or very rare in the Kalahari residues. It seems unlikely that garnet would disappear completely if the breakdown of the Pipe Sandstone or Karroo sediments had contributed substantially to the later formation. Its disappearance cannot be attributed to post-depositional influences, since the Kalahari Sands are of comparatively recent origin and have never undergone tectonic disturbance or deep burial. The type of quartz grains present, and the rare microcline and oligoclase grains, suggest that granites and metamorphic rocks contributed largely to its make up. The sporadic appearance of epidote and cinnamon-coloured sphene indicate that considerable areas of granite were exposed in the track of the drifting sands. It seems possible, therefore, that much of the bulk of the sand was derived more or less locally, from the rocks either within the Colony or across the Zambesi in Northern Rhodesia, although the small size and perfect rounding of many of the zircon grains suggests that they have either travelled a very considerable distance, or passed through more than one cycle of sedimentation.

If the evidence given above for a northerly source for the Kalahari Sands of Southern Rhodesia is accepted, it emphasizes the difference between the present climatic regime and that under which the sands were accumulated. At the present day the winds of the dry season (winter) blow with great regularity from a direction 10°–20° south of

east, and northerly winds are common during the present wet season. Conditions during Kalahari Sand times must have been very different. As part of a study of the environment of early Man in this part of Southern Africa such changes are a matter of importance, and it is likely that during most of the period during which the Kalahari Sand was deposited, much of Southern Rhodesia became uninhabitable. The question of where the human inhabitants of this country migrated in the face of the invasion of their territory by advancing sand has been touched on by Neville Jones (1948, p. 31). From purely typological considerations he has concluded that the makers of the Bembesi Culture, who lived in Southern Rhodesia just before the Kalahari Sand period, moved southward to the Pietersburg district of the Transvaal. This conclusion is in striking accord with the mineralogical evidence given above for the direction of origin of these Sands.

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CORRESPONDENCE

BATHONELLA AND *VIVIPARUS*

SIR,—Like Dr. Arkell, I am much interested in Dr. Yen's proposition of a new genus *Bathonella*, regarded as marine, for the previously supposed *Viviparus* of our Bathonian rocks. Palaeontologists will, no doubt, feel happier about accepting this genus when they know that answers are forthcoming to the questions in Dr. Arkell's letter. I should, therefore, like to make the following observations.

(1) The question whether *Viviparus* shells could be transported to the sea, either dead or alive, and embedded in a marine deposit in myriads (even predominating over associated marine species) is of some interest. I thought it would be helpful to ascertain the views of an experienced naturalist and authority on modern freshwater shells on this point. A letter from Mr. A. E. Ellis, author of *British Snails* (1926), is annexed to the present one and speaks for itself. I am aware that in formations consisting of an alternation of freshwater and estuarine strata, such as the Purbeck Beds and the Isle of Wight Oligocene, *Viviparus* shells are occasionally found associated with marine or estuarine forms. Some may be derived fossils. Beds in which *Viviparus* is abundant are invariably of freshwater origin, the associated species all belonging to freshwater genera.

(2) and (3). Dr. Arkell raises the question of the supposed species of *Valvata* found in the same beds as *Bathonella* (to adopt Dr. Yen's name) and

in marine Upper Jurassic beds. It may, however, be pointed out that the shell of *Valvata* has not so characteristic a form that the genus can be identified with certainty in marine strata. On the contrary, there are at the present day certain families of small marine gastropods, notably the Tornidae (Adeorbidae) and Cyclostrematidae, in which the shell may bear a close resemblance to *Valvata*. After examining the types of *Valvata comes* Hudleston and of *V. praecursor* Tate, of the Scottish Great Estuarine Series, I cannot define any characters by which they could be distinguished from some of the Tornidae. *V. praecursor* occurs in considerable numbers, associated with *Modiolus* and marine gastropods, along a bedding-plane of a shelly limestone. It is surely more reasonable to assume that it is a small marine shell, than a freshwater shell, multitudes of which were brought down to the sea by a river. Cossmann [1] has suggested that some of the fossil species described under *Valvata* may really be marine forms belonging to the Cyclostrematidae.

(4) In northern Oxfordshire *Bathonella* occurs only at one horizon, but in the Great Estuarine Series of Skye it occurs at intermittent horizons through at least 100 feet of marine-estuarine strata. The theory that it was swept down from inland waters in large numbers as the result of repeated catastrophes or " temporary tricks of currents " seems improbable.

(5) Dr. Arkell asks why, if the genus *Bathonella* has been separated from *Viviparus* on obvious morphological grounds, all previous workers have mistaken it for *Viviparus* ; and why Dr. Yen does not clearly state the characters which distinguish it from that genus. The reply to the first question is that previous workers have not all identified it without hesitation as *Viviparus*. E. A. Walford,[2] who made the most extensive collection from Sharp's Hill in existence, clearly doubted the correctness of Hudleston's generic assignation of " *Viviparus* " *langtonensis*, as he assigned the species to *Turbo* as an alternative to *Viviparus* and spoke of the *Turbo langtonensis* Marls. Other specimens from his collection bear the name *Turbo paludinaeformis* (? a mistake for *Turbo paludinoides* Hudleston), and under that name have long been exhibited in the Oxford University Museum. Dr. B. Prashad,[3] has remarked of *V. langtonensis* and *V. scoticus* : " These two are doubtful species of the family and were certainly not freshwater forms."

In the hope of forming an independent opinion on the matter I have (through the kindness of the respective curators) examined the syntypes of *V. langtonensis*, preserved in the Sedgwick Museum, the Sharp's Hill specimens studied by Dr. Yen, from the Richardson Collection in the Geological Survey Museum, and the Oxford University Museum specimens just mentioned. I agree with Dr. Yen that the aspect of this species differs from that of *Viviparus*. The differences are as follows :—

(i) The outline of a normal *Viviparus* shell, when viewed from the dorsal side, is conical with a slightly conoidal tendency, the actual apex being frequently obtuse. *Bathonella*, owing to its expanded and highly convex last whorl, could not be described as conical, but rather as elevated-turbinate ; its apex is acute and projecting. A line tangential to the successive whorls in *Bathonella* presents an outward-facing concavity in contrast to the corresponding convexity in *Viviparus*.

(ii) Near the aperture the last whorl of *Bathonella* has the appearance of being almost detached from the parietal wall, to which the peristome, which is continuous, adheres but loosely. In *Viviparus* there is no such apparent loosening of the embrace of the last whorl.

[1] *Essais de paléoconchologie comparée*, xi, pp. 69, 73 (1918).

[2] *New Oolitic Strata in N. Oxfordshire*, pp. 8, 14, 16, 27 (1906).

[3] " Recent and Fossil Viviparidae. A Study in Distribution, Evolution and Palaeogeography," *Mem. Indian Museum*, viii, p. 198 (1928).

(iii) The aperture of *Bathonella* could be described as nearly semicircular in shape, with the columellar lip (much straighter than in *Viviparus*) forming the diameter. That of *Viviparus*, on the other hand, is inverted-pyriform owing to a tendency to be contracted where the outer lip joins the parietal wall.

(v) The test of *Bathonella* is appreciably thicker than that of *Viviparus*.

It may be added that the main distinctive features of *Bathonella* are shown in Cossmann's [1] figures of " *Viviparus* " *aurelianus*, which I have no doubt is identical with our British species, *Bathonella scotica*, of which " *Viviparus* " *langtonensis* is a synonym.

(6) A glance through the literature will show that these Bathonian forms are not the only *Viviparus*-like species to have been found in marine Mesozoic beds. Several such species have been assigned to *Turbo* ; among them, *T. imperati* Stoppani,[2] of the Trias, *T. viviparoides* Roemer,[3] of the Upper Jurassic, and even *T. paludinoides* Hudleston,[4] of the Inferior Oolite. *T. gibbosus* (Thorent),[5] of the Inferior Oolite is only slightly more depressed. Shells such as these, with smooth, evenly convex whorls are, in fact, almost the simplest type of coiled gastropod imaginable, and it is not surprising to find them affording examples of parallelism between marine and freshwater genera.

L. R. Cox.

British Museum (Natural History),
London, S.W. 7.
13th July, 1948.

Annexed Letter

Dear Cox,—In reply to your letter of 6th July, I should regard it as quite impossible for any freshwater shells to float downstream and become incorporated in marine deposits in any quantity. Shells of *Viviparus* do turn up with others in the refuse left by receding floods, and no doubt some might get eventually carried out to sea before they sank. I should say the chance of finding a freshwater shell in a marine deposit is exceedingly remote, particularly as there is a " no-man's land " of brackish water separating the fresh water of rivers from the sea, and the fluviatile species die out, in the case of larger rivers, several miles above the estuary. If these *Viviparus*-like shells in your Jurassic bed are present in quantity, they must, in my view, have lived more or less where they now lie.

Although I have sometimes seen odd *Viviparus* shells floating in a canal, they usually never float at all. The snail dies on the bottom, where the shell remains. This always happens in aquaria—the empty shell does not float, as it never gets air-filled. Gases of decomposition might make it buoyant for a time, but I think you can eliminate the possibility of the shells being water-borne long enough to be dumped at sea in bulk.

A. E. Ellis.

Epsom College,
Epsom.
7th July, 1948

[1] *Bull. Soc. géol. France* [3], xxvii, pp. 141 (text-figs.), 565, pl. xvii, figs. 2–7 (1899–1900).

[2] *Pétrifications d'Esino*, p. 65, pl. xiv, fig. 14 (1859).

[3] *Versteinerungen des norddeutschen Oolithen-Gebirges*, p. 153, pl. xi, fig. 3 (1836) ; also Brösamlen, *Palaeontographica*, lvi, p. 232, pl. xix, fig. 6 (1909).

[4] " Inferior Oolite Gasteropoda," p. 355, pl. xxix, fig. 2 (1894).

[5] D'Orbigny, *Paléontologie Française, Terrains Jurassiques, Gastéropodes*, p. 342, pl. cccxxx, figs. 1–3 (1853).

THE VARIATION OF *RHYNCHONELLA BOUETI*

SIR,—It was with great interest that I read the letters referring to the variation study of *Rhynchonella boueti* by Mr. W. G. Aitken and myself (*Geol. Mag.*, lxxxv, 1948), which you published in your May–June number.

Mr. R. K. Blundell's diagram exhibits the variation of the ratios L/T, T/B, and L/B in a very similar way to our Text-fig. 10; and I would readily agree with him that only two, and not three, independent variables are, in fact, represented—his diagram indicates this clearly. The only advantage of drawing the axes at 60° (as in our Text-fig. 10) is that the three ratios are then equally represented, whereas if two axes are taken at 90° to each other one set of ratios is bound to be on a different scale to the other two (e.g. in Mr. Blundell's figure the distance between the lines L/B 0·8 and L/B 0·9 is only three-quarters the distance between the lines T/B 0·8 and T/B 0·9). I may add that I am gratified to find that his scatter confirms so completely our own findings.

In reply to Mr. F. W. Beales I would say that quite certainly the specimens we used did not in all literalness belong to a community of strictly contemporaneous individuals; but, geologically speaking, the Boueti Bed is so thin (1 foot) and the areal range of the collection is so limited (10 yards along the line of outcrop), that if fossil communities are ever to be recognized, substantially this was one from which our sample was taken. Evidence of exposure of the shells for any length of time, as proved by polyzoan and serpulid incrustations, has no relevance, since a collection of present-day shells on a present-day beach may well show similar overgrowths.

W. S. MCKERROW.

DEPARTMENT OF GEOLOGY,
UNIVERSITY MUSEUM, OXFORD.
15th July, 1948.

THE RANGE OF *THYSANOPHYLLUM PSEUDOVERMICULARE* (M'COY)

SIR,—In a forthcoming paper in the *Transactions* of the Leeds Geologists' Association I have recorded the presence of *Thysanophyllum pseudovermiculare* in a reef-knoll at Ballykane Hill, Co. Kildare, and suggested that the knoll in question may be early C_2 and so intermediate in age between the C_1 reef-limestones of Co. Dublin and those of C_2 age near Cork. Since passing page-proofs, I have found a number of corallites of the species at Stepsbeck Bridge, Scandal Beck, Ravenstonedale, at an horizon between the *globosus*-Band and the underlying Algal Band, and so far below the well-known *pseudovermiculare*-Band of C_2. Dr. C. J. Stubblefield has drawn my attention to what appears to be a still earlier occurrence of the coral, viz. in association with *Solenopora garwoodi* and *Camarotoechia proava* in Dukes Wood well no. 146 (Lees and Taitt, 1946, *Q.J.G.S.*, 101, p. 281). Accordingly, there is no reason to regard the Ballykane Hill knoll as younger than the C_1 reefs of Dublin, to which its brachiopod-fauna is allied.

I am indebted to Dr. Stanley Smith for identifications of the Kildare and Ravenstonedale corals: he informs me that M'Coy's species should be referred to the genus *Spongophyllum* Edwards and Haime, 1851.

J. SELWYN TURNER.

DEPARTMENT OF GEOLOGY,
UNIVERSITY OF LEEDS.
17th August, 1948.

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The New Red Sandstone of South Devonshire

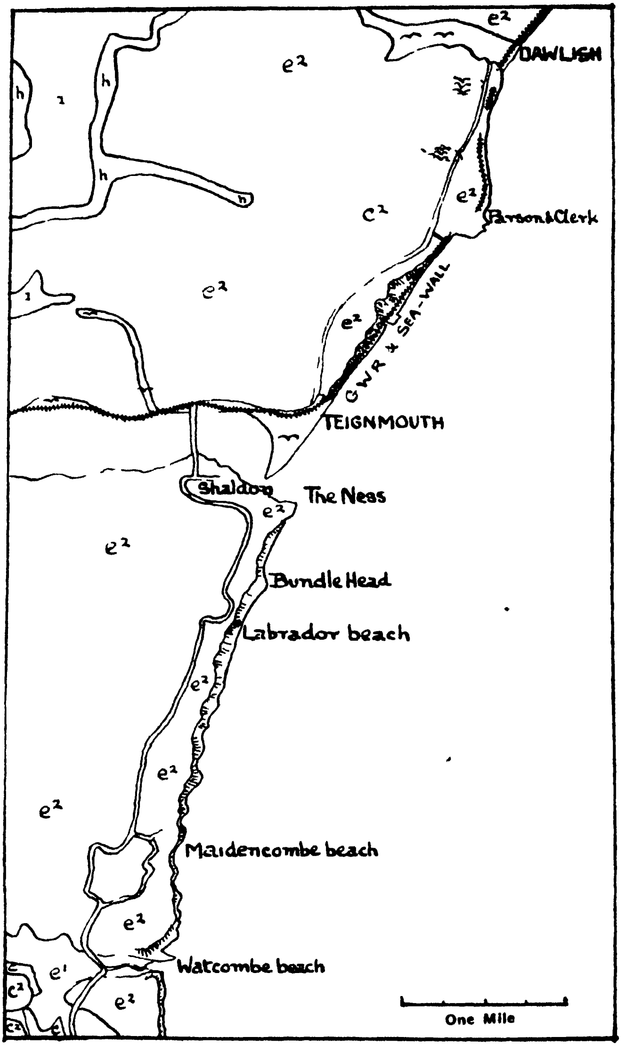
By J. B. SCRIVENOR

(PLATES XVIII AND XIX)

THE objects of this paper are to supplement previous descriptions of the coast sections of the New Red Sandstone from Exmouth to Oddicombe, and to discuss views of the origin of the rocks as stated in the following quotation from the revised Torquay Memoir (Ussher-Lloyd, 1933, p. 105): "It is generally accepted that the lower New Red Sandstone breccias result from continental conditions, in which the extremes of temperature and recurring torrential rainfall operated on the bare slopes of a mountainous region, to produce diluvial fans, similar to those now being formed in the mountain valleys of Kashmir and Persia. The Dartmoor granite no doubt once formed an elevated dome and from this high ground, much higher and more extensive than at present, torrents flowing in a general easterly direction would produce gravelly accumulations, composed largely of the angular debris of formations then exposed. These accumulations may in part have been swept into a lake and there mixed with, or alternated with, beds of sand deposited under normal conditions; wind-borne sand may also have been blown from the desert into this lake or inland sea." The term "diluvial fans" was introduced by Lloyd into the revised memoir, obviously without any reference to Pleistocene glacial deposits or the Deluge of Noah, as might be suspected from the use of this old word "diluvial". "Alluvial fans" is preferred here and no evidence has been found of glacial action at any time.

The terms "breccia", "breccio-conglomerate", and "conglomerate" have been used for stony beds in these strata, and reflect doubt as to their application. Norton (1917) could justly claim some beds as breccias, e.g. the top right hand part of fig. 1, Plate XVIII; but figs. 2 and 3 of the same plate, characteristic of most of the stony beds, are neither typical breccias nor typical conglomerates. The Librarian of the Geological Survey helped me to look through numerous photographs of conglomerates and breccias. In some cases a rock called a breccia might equally well have been called a con-

glomerate ; but there was no doubt about the basal breccia of the Lower Old Red Sandstone at Kerrara, Oban, being a typical breccia of angular blocks jumbled up with little matrix. It is hoped that the photographs will illustrate the difficulty of applying these three terms



TEXT-FIG. 1.—Sketch-map showing the chief localities and outcrops on one inch sheet 339 : c = Devonian slates and shales ; c^2 = Middle Devonian limestone ; e^1 = Watcombe Clay ; e^2 = New Red Sandstone ; h = Upper Cretaceous ; i = gravel of Haldon ; ≋ = valley gravel ; ⌒ = alluvium.

to the stony beds. To obviate it the term " stony sandstone " will be used here. Two authors, E. Hull (1892, p. 60) and A. Irving (1888, p. 157) wrote of the beds being " brecciated ", giving a quite wrong impression. The stony sandstone contains pebbles, cobbles, and boulders. B. Hobson (1906, p. 314) measured a boulder of 93 cubic feet. The largest I measured was 48 cubic feet. Both were at Bundle Head. As a whole the New Red Sandstone here consists of sandstone, stony sandstone, and loam.

The field-work on which this paper is based was carried out in 1934, 1937, and 1947. I am indebted for assistance and suggestions to the staff of the Geological Survey, the Head Master of Bedford Modern School, Dr. R. Churchill Blackie, Dr. W. F. Hume, Dr. F. T. Ingham, Mr. T. V. Scrivenor, Dr. W. E. Swinton, and Professor L. J. Wills.

It is hoped that the photographs will give a better idea of these beds than a long description. The rocks are distinctly stratified and with certain exceptions of a deep red colour, resembling the streak of haematite. At Dawlish cross-bedded sandstone is of a lighter, orange colour ; at the north end of the sea-wall (Teignmouth), in the cliffs from Shaldon to Labrador Beach, and high up on the north cliff of Maidencombe, thin white beds are plainly visible ; while on the beach at Shaldon I saw one boulder of sandstone partly red and partly grey. The thin white beds (Plate XIX, fig. 2) are easily accessible except at Maidencombe.

W. Pengelley (1863) determined carefully a long series of dips from Saltern Cove to Exmouth and gave the average dip as 15½° towards 44½°, i.e. practically north-east. The only emendations this list requires are the addition of more figures for the coast from the beach south of Labrador to the Ness, in order to show that here the beds are almost horizontal and more figures for dips along the sea-wall at Teignmouth. At low tide rock-platforms are exposed at Labrador Beach with a gentle slope of about 5° north-east and east-north-east. At the Ness, Pengelley gives the dip as 5° towards 129° Mag. then equivalent to 105½° true bearing. On the north of the Teign the dips are higher, about 15° to the north-east. In Pengelley's figures for the amount of dip a rhythmic decrease from south to north is roughly indicated ; first 17° at Saltern Cove to 4° at Livermead Head ; then 37° at Oddicombe where, however, the beds are clearly faulted down between masses of Devonian limestone, to 5° at the Ness ; lastly, a maximum dip of 35° recorded by Pengelley between Teignmouth and Dawlish to 5° at Exmouth. Any possible connection between these dips and alluvial fans will be discussed later.

The distribution of the cobbles and boulders in the sandstone is shown in the photographs. The commonest are of Devonian limestone, quartz-porphyry, and granite-porphyry. On Labrador Beach boulders

of white limestone are conspicuous. The stony sandstone beds are sometimes lenticular and at Oddicombe show rough cross-bedding. The most stony beds form headlands, Bundle Head, the Ness, and the Parson and Clerk ; but it is noteworthy that the largest boulders of limestone and quartz-porphyry occur at Bundle Head and the Ness, Bundle Head being 2¼ miles from the nearest (small) outcrop of Devonian limestone east-north-east of Bishopsteignton ; 2¾ miles from quartz-keratophyre west of Bishopsteignton ; and 9 miles from the Dartmoor granite. The boulders of quartz-porphyry are so large and so numerous that the parent rock cannot be far away .

The Watcombe Clay has been regarded as the base of the New Red Sandstone here. It is an orange-coloured clay well exposed on Watcombe Beach and in the adjacent pottery-works. On the beach it lies under stony sandstone ; but as it shows no bedding the question whether it is conformable or not could not be settled. H. Dewey (1935, p. 39) mentions " Watcombe Clays and sandstone (shale paste), 0–200 feet ". W. Lloyd (1933, p. 107) mentions shaly marls and comminuted Devonian slate with, here and there, clay with fragments of Devonian limestone. W. A. E. Ussher (1877, p. 298) said that in Watcombe Cove the clay assimilates to a shale and that near the path to Petit Tor Beach the origin of the clay was explained by the presence of lilac-brown Devonian clay-slates and shales. I thought that the clay suggested much weathered shale and its colour recalled clay on dissolving limestone, though not so dark as in Malaya and Sarawak. It is possible that the Watcombe Clay is not the base of the rocks believed to be Permian, but weathered Devonian argillaceous rocks, mixed perhaps with residual clay overlying Devonian limestone.

Ussher (*loc. cit.*) also mentioned annelid tracks in the sandrock above the clay in Watcombe Cove. Pengelley (1863, p. 34) described cylinders in the sandstones and speculated on borings by animals in the sand. He said they are numerous at Watcombe and referred to similar things east of Exmouth. I do not doubt the accuracy of these observations ; but at Watcombe I only saw secondary cellular growths of limonite on joint faces in fallen blocks of stony sandstone.

Lloyd (1933, p. 105) seemed in favour of a lateral passage of coarse sandstone into the marls and sandstones north of the Exe. The great thickness claimed by earlier authors is perhaps unjustified and the series may represent comparatively thin sloping, subaqueous deposits not greatly disturbed by earth-movements since their deposition. Ussher (1913, p. 83) quoted a bore at Teignmouth Waterworks totalling 332 feet, but the thickness must exceed 400 feet at least. The road from Teignmouth to Torquay touches the 400 feet contour at the head of the steps leading down to Labrador Beach. Close to the steps one can look over the sheer red sandstone cliff and see

buildings on the site of the old Labrador Inn, and the beach beyond. As the beds here are almost horizontal, denudation at the top of the cliff and rock exposures below high tide mark postulate a thickness of more than 400 feet.

The degree of cementation varies. Some of the strata are sufficiently hard to be used as building-stone. The cement is almost always ferruginous. Thomas (1909, p. 236) said that it is only calcareous in the vicinity of limestone masses and that a completely siliceous cement never occurs. Austen (1842, p. 455) mentions manganese.

Examination of the white beds with adjacent red sandstone had the following results. Fig. 2, Plate XIX, shows these white beds near Bundle Head. The maximum thickness measured was 2 inches; but those high up on the Maidencombe cliff look thicker. Near Shaldon I saw a 2 inch red bed that changed laterally and abruptly to white for 4 inches and then changed back to red without any gradation of colour. The white beds are sometimes close together and connected by vertical or inclined bands or have irregular offshoots. Detached white patches, as seen in section, also occur. The white rock can be cut with a knife, the cut surface being clayey. Nowhere did I see gradation of colour between a white and red bed: the division is always sharp.

The dry rock is friable, both red and white; when immersed in water it disintegrates, therefore cementation must be weak. The white rock was found to contain sand-grains, chiefly quartz, up to 0·6 mm. diameter, with much clay. The sand-grains are normally worn. No "millet-seed" grains were seen. Calcium carbonate was not found and no gypsum was identified, either optically or chemically. Thomas (*op. cit.*, p. 231) mentions barytes and celestine in his list of minerals, but not gypsum. Some of the finest clay seems to be colloidal. This rock is white loam.

The red rock in the specimen examined is loam and sandstone. The change in colour was found to be not entirely coincident with the bedding, i.e. part of the white loam bed was red in continuation with the adjacent red loam bed. The sand-grains in the red sandstone measured up to 4 mm. Disintegration when standing in water was complete in half an hour, and the red dust of the cement was easily separated by decantation, taking two hours to settle. I measured particles of 0·7 microns but there was finer material. Much appeared to be colloidal. Neither in the white nor in the red rock did I see any trace of micro-organisms in spite of prolonged search. The coarser material from which the red cement had been decanted consisted largely of angular pieces of red-brown shale up to 4 mm. in diameter. When cut they showed a white interior unless very thin. The red rock contained one shale pebble of 20 mm. diameter that was found to be red and ferruginous throughout. Angular quartz-grains occurred:

one rounded grain was seen, also angular black grains and one rounded. A few skeletal grains were seen suggesting an oxidized sulphide.

A weighed portion of the red sandstone was boiled in hydrochloric acid, the loss due to matter going into solution being 10 per cent; and I did not obtain any reaction to show that anything but iron oxide had been dissolved, probably all Fe_2O_3, but it may be partly hydrated. The red rock treated with acid contained clay and I expect that much of the rock called sandstone in the cliffs is really loam; but I did not see any beds of pure clay. Lloyd (1933, p. 107) mentioned lenticles or pockets of clay in the Paignton neighbourhood as being common. In all the specimens examined by me, white mica occurs sparingly.

I am indebted to Dr. W. E. Swinton for arranging for me to examine, in one of the damaged galleries of the British Museum (Nat. Hist.) a slab of sandstone with footprints from Poltimore, to the north-east of Exeter. This, and other slabs now in the Royal Albert Museum, Exeter, were described by Clayden (1908, two papers) who considered the sandstone to be the base of the whole New Red Sandstone series in that locality. He said that some of the quartz-grains were very perfectly rounded; mentioned suncracks, ripple-marks, and a suggestion of wind-blown dust preserving the footprints (second paper, pp. 498, 500). The rock in the British Museum is firmly cemented fine grained sandstone. Well rounded dark grains are visible with a hand lens, and I have no reason to doubt Clayden's statement regarding rounded quartz-grains.

Some points concerning the igneous rocks found as boulders require a short notice here. In the list of igneous rocks given by Shannon (1927 and 1933, Paignton, Torquay, and the River Teign being included in the main regions examined, see 1927, p. 133) granite is not mentioned; in fact, he says " granite has not been identified " (1933, p. 104). At Bundle Head, however, and on Labrador Beach, boulders of granite-porphyry with felspar phenocrysts up to 5 inches in length are common, and on Labrador Beach I found one boulder that could not be distinguished from the porphyritic granite of the West of England. The large felspar phenocrysts are cloudy. I did not see in these boulders any of the flesh-red murchisonite crystals first described by Levy (1827). In his earlier paper (1927, p. 144) Shannon wrote: " The reddened rocks and the fresh felspar show that the region was arid for long intervals." A specimen of quartz-porphyry collected on Labrador Beach as representative of many shows glass-clear felspar phenocrysts accompanied by others partly or completely decomposed. I am much indebted to Dr. K. C. Dunham and Mr. T. G. Jones, of the Geological Survey staff, for examining cleavage flakes of the fresh felspar. The latter determined the specific

gravity as 2·555; and Dr. Dunham sent the following note on the optical properties; "biaxial, negative with very low 2E, not exceeding 10°; $\alpha = 1{\cdot}517$, $\gamma = 1{\cdot}524$; evidently a sanidine." Dr. Dunham also kindly looked through slides of elvans and found one with sanidine that came from Darley Mine, 2½ miles south of North Hill village, 1 inch map 337; 6 inch map Cornwall 28 N.W. This elvan also contained fresh sanidine and decomposed felspar side by side. Sanidine, as is well known, generally occurs in effusive rocks. I have not found a reference to any other case of it in quartz-porphyry; but Pecora (1942) described sanidine in nepheline-syenite-pegmatite of Montana; and I have a very old note of beautifully fresh orthoclase and soda-plagioclase in quartz-porphyry used in building a beacon in Singapore Harbour (Geol. Sur. Malaya, 922). As petrological detail was unnecessary for this paper I did not have any sections cut; but Dr. Dunham, to whom I had sent a piece of the quartz-porphyry from Labrador Beach, kindly had a slide prepared (E. 22063) and his description of it shows points of resemblance to this Singapore rock. He finds oligoclase in addition to the sanidine, biotite, pseudomorphs in iron oxide after biotite and possibly after hornblende. Biotite and hornblende occur in the Singapore rock. The decomposition product in the Labrador Beach quartz-porphyry is probably kaolinite; but Dr. Dunham, in reporting this, tells me that in the North Hill elvan the felspar other than sanidine is sericitized.

There is also a mineralogical point to be noted. When H. H. Thomas wrote on the Budleigh Salterton Pebble Bed (1902) and later on the petrography of the New Red Sandstone (1909), no staurolite was known in the older rocks of the West of England from which the staurolite in either could have been derived. Tilley, however, in 1937 (p. 307), recorded staurolite in granulites at Pistil Ogo, The Lizard.

There is no doubt that the Devonian and Carboniferous rocks of the West of England were greatly affected by folding and shearing. It is believed that this resulted in the formation of an Armorican mountain chain or parallel chains, the most northerly being one trending from South Eire, South Wales, to the Kent coalfield and on to the Ardennes, a little north of west and south of east. The comparatively undisturbed New Red Sandstone is separated from the older rocks by a sharp unconformity, but how long a time interval it represents we do not know; and the age of the stony sandstones is uncertain, whether they are Permian or Triassic. Lloyd and Shannon are quoted above as mentioning the following points about the post-Carboniferous land-surface: (1) a mountainous region; (2) recurring torrents flowing eastward and forming alluvial fans of gravelly accumulations; (3) extremes of temperature; (4) arid conditions for long intervals, shown by reddened rocks and fresh felspar.

To this must be added the rounded sand-grains mentioned by other authors ; (5) a lake or inland sea into which part of the alluvial fans may have been swept and mixed with water-borne and wind-borne sand.

Study of this picture of a very early Devon and Cornwall has led me into an interesting and delightful field of literature both scientific and popular. Some of the books and papers consulted are listed below in the Bibliography. The picture is rather confused because it contains two scenes superimposed one on the other : a mountainous scene with deep-cut valleys and alluvial fans as in the Himalayas ; and an arid, red desert scene with a lake such as is known in Central Australia.

Certainty about this palaeogeography of Devon and Cornwall is impossible, but the conclusions I have arrived at on the evidence available are that alluvial fans are not proved ; there is no evidence of extremes of temperature or of arid conditions ; a large body of water existed in which the New Red Sandstone was formed as beach and shelf-deposits, derived mainly from cliffs and perhaps islands as the sea advanced westward ; the deep red and uniform colour of the strata is due to two factors ; the land was lateritized and above the Devonian limestone was red or orange residual clay, and the water in the lake or inland sea was highly charged with iron in solution that was precipitated as ferric hydrate or oxide and made life impossible (cf. R. H. Rastall, 1930).

Taking Lloyd and Shannon's points in the order given above : Clayden, in his attractive book on the history of Devonshire scenery, gives a map (1906, facing p. 62) showing an ideal restoration of post-Carboniferous geography. This portrays the Mendip Armorican Range with mountains extending northward along the east border of Wales and mountain masses in north and south Devon separated by the tongue of New Red Sandstone that projects westward at Crediton, and extending southward into the English Channel. That these mountains may have existed cannot be denied and they are attributed to complications caused by " Pennine folding " ; but unless it is assumed against the trend of current opinion that the poles then occupied positions far different from those of the present day, high mountains in these latitudes would be glaciated, and there are no striated boulders or pavements, and no boulder-clays to support the existence of glaciers. In an earlier paper (1941, p. 138) I compared the New Red Sandstone of Dawlish and Teignmouth with the Gopeng Beds of Malaya ; but the latter are much more clayey and I abandoned, for other reasons, my first view that they were of glacial origin.

The possibility of torrents forming alluvial fans has been considered in connection with the rhythmic decrease in dip shown by Pengelley's records (*supra*). The first section of the coast is from Saltern Cove,

south of Paignton, to Livermead or Corbons Head, north of Paignton. The coast outcrops are separated by long sandy beaches and on that account are not of much value in this connection. The second section is from Oddicombe to the Ness, the exposures being continuous except for a short break at Petit Tor. If the original dip of the beds in the Oddicombe cliffs has not been affected by the faulting down between masses of Devonian limestone, there is a distinct decrease of dip up to the Ness, but Pengelley's figures for the direction of dip do not show the radial structure one expects in a fan. In the third section, from Teignmouth Bridge to Exmouth, the irregularity of the amounts of dip given by Pengelley between Teignmouth and Dawlish does not accord with its regularity of about 15° all along the sea-wall up to the first tunnel, possibly because his dips were recorded before the sea-wall and railway were constructed and when the present exposures were non-existent. If that is the case his dips must be chiefly on the Parson and Clerk Headland and confined to a small part of this section with lower dips on either side. The directions of dip shown by him again present no radial structure. If the three sections are connected with alluvial fans the latter must have been of considerably large extent. I have searched publications for examples of large ones. Blanford (1873) described fans in Persia that merged into piedmont plains, and said that boulders extended from five to ten miles from the base of the hills where the fans originated. Boulders of 2–3 feet diameter were not rare a mile or two from the hills. Drew (1873 and 1875) gave an excellent account of the alluvial fans in the Indus Valley with clear drawings. He described one (1873, p. 445) with a radius of about a mile. Opposite Leh are many fans joined together, extending for thirty miles and nearly two miles in radius. Dainelli (1932, facing p. 234) gives a photograph showing part of these fans. In Mongolia, Berkey and Morris (1927) described fans on the northern slope of Baga Bogdo; their Plate XXX shows one fan five miles from apex to base and another of eight miles. Judging from Younghusband's description, however (1937, pp. 74 and 75), of the other side of these hills, rock-disintegration without denudation by rain has been a factor in the formation of these fans. Longwell (1928) has described a remarkable "fanglomerate" in the Muddy Mountains of Nevada with an outcrop along the dip of about four and a half miles, but it may have been more originally. In this fanglomerate the boulders, etc., are jumbled up together with hardly any trace of bedding. These examples of extensive fans show that such fans may have entered into the formation of the New Red Sandstone, but the absence of radial structure makes it doubtful.

Extremes of temperature occur in hot desert regions and in some mountains. In the former they result in split and cracked boulders

such as are figured by Walther (1912, pp, 60, 132, and 133); in the latter large screes of sharply angular rocks are formed. I have not seen evidence of either case in the New Red Sandstone of Devon.

Arid conditions for long intervals, shown by reddened rocks, fresh felspar, and rounded grains of sand. There is some uncertainty about the definition of a desert but although in Africa at any rate, redness such as that of the New Red Sandstone in Devon is rare, Australia provides very extensive red deserts with red sand-dunes and red dust being blown out to sea along the Ninety Mile Beach of Western Australia by the South-East Trade Winds. My son, T. V. Scrivenor, who travelled in 1945 and 1946 by air across North Africa, between Cairo and the Cape, Khartoum and Accra, and by land in Kenya, Uganda, and Somaliland, gave me isolated examples of red sand, but said that the deserts he crossed were mostly tawny. One passage in his letter is apt to the present discussion: " Much the reddest soil I have seen was in Uganda and other parts of East Africa where the redness is quite startling in contrast with the surrounding greenery. But those parts of the world are very lush, there's nothing sandy about them. . . ." It is a mistake to think that redness is necessarily caused by arid conditions. In Australia there is a strong opinion that the redness of the deserts is due to an earlier formation of laterite when the rainfall was much heavier than now (G. Taylor, 1940, p. 82). In the equatorial East the formation of red laterite is due, not to aridity, but to high rainfall and high temperature. When the extensive laterite of Australia was formed the climate was probably similar. Therefore the redness of the New Red Sandstone of Devon and the lateritized shale and pebbles point, not to aridity, but to a warm, moist climate.

Fresh felspar has been adduced as evidence of a cold and of an arid climate. Its significance here is of small if of any account, because felspars differing little in chemical composition, judging from their optical properties, can be seen perfectly fresh and completely decomposed in the same boulders. Moreover, the Singapore quartz-porphyry mentioned above, quarried somewhere near its present position, has fresh felspars in a climate that is far from dry now and which we have no reason to believe was ever dry.

With regard to the rounded sand-grains, Thomas (1909, p. 235) said that in the beds of sand and sandstone intercalated with the Lower Breccias the grains were always well worn, usually more so than those of ordinary marine or dune-sands of coastal regions, " in fact, many samples approximate very closely to the ' millet-seed ' sands of deserts." It is possible to pick out rounded grains in the intercalated beds I have described above, but the same is true of the alluvium of the Great Ouse near Bedford. Millet-seed sands are,

I believe, confined to moving dunes in which the grains are continually rolling down a slope. Desert sands apart from moving dunes are generally angular or subangular (cf. Sujkowski, 1932, pp. 312, 313; Hume, 1925, plates XXI, figs. 36, 37; XXII, fig. 41; Gregory, 1906, photograph on cover; la Touche, 1911, p. 40), though a few rounded grains occur. The dune-origin of the Penrith Sandstone is not questioned; but in Devon rounded grains may have been derived from quartz-blebs in the quartz-porphyry and sand churned in potholes of the Devonian limestone.

In a warm, moist climate red or orange residual clay might accumulate over dissolving limestone and add its quota to the iron oxide in the New Red Sandstone by denudation.

The existence of a body of water in which the New Red Sandstone was deposited is mentioned by many authors. Clayden's map shows the dimensions he assumes for it. Its greatest length is about 400 miles. Its width in the Devon area is about 50 miles. Compare with these figures the dried-up Lake Eyre, in Central Australia, about 110 by 50 miles: the Lake of Geneva, about 37 by 9 miles: Lake Superior, about 350 by 140 miles. Lake Eyre, so well described by Madigan (1936), is thought to have been formerly ten times as large and filled with fresh water flowing southward to the sea. Now it is separated by an isthmus into a small southern portion and a large northern portion, much as Clayden's Devon lake is shown as nearly separated from a larger Y-shaped body of water in the north by large islands on the axis of the Mendip Armorican Range.

Everything I have seen makes me think that these sandstones and stony sandstones are beach (see Plate XIX, fig. 1) and coastal shelf-deposits laid down in a body of water that gradually cut its way westward and at the same time rose in level. This removes any difficulty about the derivation of material, e.g. the murchisonite felspar, and transportation of large boulders over long distances. The boulders were broken from cliffs and perhaps islands by the water as it advanced; but at the same time rivers brought alluvium from the land on the west together with much iron oxide from the lateritized rocks. The angularity of many of the boulders and cobbles may be due to the width of the body of water having been insufficient for very heavy seas or to their having been mixed with sand on the beach. I have a picture-postcard of a beach at Mullion showing sand and subangular boulders (one curiously shaped like a large *dreikanter*), Anyone walking along the sea-wall at Teignmouth when the tide is out can see boulders derived from the New Red Sandstone lying in sand, so even if the width of the post-Carboniferous water was far in excess of 50 miles, which is quite possible, the boulders might still have been subangular.

The uniformity of the deep red colour of the New Red Sandstone is difficult to explain, and connected with it is the problem of the origin of the thin white beds. Taking the latter first, the obvious explanation might appear to be reduction of the iron oxide; but in Plate XIX, fig. 2, there is a fault-plane and some joints (see legend) that show no reduction; therefore, if the white beds are due to reduction, it must have taken place before the fault and joints were formed. Again, if it is a case of reduction of ferric oxide why do not the beds show green coloration due to ferrous compounds, like the tea-green marls north of the Exe? Another objection is that the white beds contain much clay: why should the reducing agent have attacked them and not the more pervious beds? Parfitt (1875) appears to be the only author who has mentioned these white beds. He explained them as a result of the decay of flat plates of limestone included in the strata and said that he found thin pieces of limestone in various stages of decay (*op. cit.*, pp. 326–8). He quotes Godwin Austen (1842, p. 455) as saying: "wherever limestones, blocks, and pebbles occur (as about Teignmouth), the materials which surround them are not coloured." I saw only one limestone boulder with whitish material round it. This may be due to solution of the limestone. As for Parfitt's explanation, I have not seen anything to support it.[1] Rhythmic

[1] *Parfitt quoted from the following passage in Austen's paper which is worth giving in full: "The bright red colour of the formation, particularly the South Devon portion of it, has not been satisfactorily accounted for. The colouring metals are iron and manganese, but the latter only in small proportion; and it may be some help towards the solution of the point to mention that wherever limestone blocks and pebbles occur (as about Teignmouth), the materials which surround them are not coloured. Now either the whole mass was red throughout, and the colour of the portions in contact with the limestone subsequently discharged, or the colour must have been at some time subsequent to the accumulation of the deposit imparted to all the mass, except to such portions as happened to be in contact with fragments of limestone; the latter supposition seems most reasonable. If we examine the coloured portions, we observe that each particle is coated with a thin pellicle of peroxide of iron: now as this could not have been held in solution by the water which collected the materials we must suppose that the conditions under which they were subsequently placed, favoured the conversion of the iron contained in the abraded porphyritic rocks, and at first only mechanically disseminated throughout the mass, into colouring matter for the whole of it, with the exception already noticed."*

Briefly, Austen thought that the red colour was due to iron oxide derived from the quartz-porphyry boulders and cobbles. He did not realize that iron could have been brought in suspension and solution from land. The thin pellicle of iron peroxide that he mentions on "each particle" is generally very thin on sand-grains but less thin on included lateritized shale; in fact, the latter sometimes have a polished appearance as in lateritized countries of to-day.

Before reading Austen's paper I had considered whether the red loam beds had been white and coloured subsequently by iron deposited from solution. Plate XIX, fig. 2, does not support that view; in fact, it seems impossible that this process could have left the vertical and inclined bands between the horizontal white beds. These vertical and inclined bands strongly suggest a reducing agent percolating along bedding-planes and wandering between them.

deposition of iron oxide and silica as described by Twenhofel (1932, pp. 431, 434, 530) has been considered, but obviously the white beds are mainly sedimentary, while the vertical and inclined white bands do not support this. Moreover, the only objects showing that silica was in solution in the water are the pieces of limestone covered with chalcedony and named "beckite" (Pengelley, *op. cit.*, part ii, pp. 18 and 19 ; Twenhofel, *op. cit.*, p. 533). The only suggestion I can make about these white beds, vertical bands, and irregular spots is that some powerful reducing agent removed iron oxide shortly after it was deposited and before the joints and faults came into being. There is no trace of organic remains that could have effected the reduction ; but the parti-coloured boulder of sandstone at Shaldon may be a case of reduction by decaying animal matter on the shore.

When considering the uniformity of the red colour of these rocks, the following possibilities should be borne in mind ; detrital iron oxide derived from the land ; wind-borne sand ; and precipitation of iron oxide or hydrate from solution. The first can be accepted as certain ; the second is improbable ; but in either case some variation of the colour parallel to the bedding might be expected in over 400 feet if they alone or one of them were the cause of the colour. The uniform colour and the presence of colloidal iron oxide may be explained by the precipitation of iron from solution as oxide or hydrate by electrolytes in the water, concurrently with sedimentation (cf. Twenhofel, *op. cit.*, p. 434). Possible sources of the iron are mineral deposits ; the culm of the Carboniferous rocks that may have contained much pyrites reduced from solution by the carbon ; and, according to Twenhofel (*op. cit.*, p. 431), some iron may have been carried from the land as organic colloid compounds. In connection with the culm I remember a reservoir in Pahang excavated in carbonaceous shale so rich in microscopic crystals of pyrite that the water was unpotable. Colloidal ferric hydrate was precipitated.

To sum up so far, my suggestion is that a body of water, containing enough salt to provide electrolytes to precipitate iron oxide, advanced westward forming beach and shelf-deposits from the cliffs and perhaps islands that it broke down, and that with this detritus was mixed sedimentary material brought by rivers from a warm, moist lateritized land, together with more iron with a little silica in solution or colloidal state in those rivers.

This, however, only applies to the rocks south of Exmouth. To the north are marls with veins of gypsum and casts of cubic crystals believed to have been sodium chloride (Clayden, 1906, pp. 101, 102, and plate facing p. 95). These cannot denote the extreme aridity that now exists round Lake Eyre, where salt and gypsum are abundant,

but they may show the beginning of arid conditions. In addition, we have the Budleigh Salterton pebble-bed, which has some resemblance to the Tehuelche pebble-bed of Patagonia. That part of South America is sometimes called " The Great Shingle Desert ". Finch and Trewartha (1942, p. 191) classify it as an exceptional middle latitude desert ; but my experience of it was that only parts deserved the name of desert at all. In the Budleigh Salterton pebble-bed quartzite pebbles with Ordovician fossils have been cited as evidence of a main southern source in the Grès de Mai. This was supported by the supposed absence of staurolite in the West of England and its presence in the pebble-bed, but now staurolite has been found in Cornwall (*supra*). The Tehuelche pebble-bed is a beach-deposit with a maximum recorded thickness of 212 feet where associated with a boulder formation 110 miles from the coast near the Santa Cruz River (C. Darwin, 1891, p. 221) and about 20–35 feet near the mouth, spread by the sea retreating eastward from near the Andes. The pebbles are well rounded (see Caldenius, 1940, for a recent description). Calcium carbonate and gypsum occur in it. Clayden (1906, pp. 98 and 99) described the Budleigh Salterton pebble-bed, compared it with the Bunter pebble-bed of the Midlands, and thought that the pebbles were transported from Brittany either by a river or by wave action. The latter seems the more likely. We know how shingle is swept along our shores to-day. When Thomas was doing his work on the Budleigh Salterton pebble-bed I was doing similar work in 1899 and 1900 on the Bunter pebble-bed of the Midlands in the same laboratory at Oxford, but could not arrive at any conclusion about the source. A few of my slides still survive and show that the sand-grains are more rounded than in the Devonshire rocks described above.

No reference has been found to recent or Pleistocene beds round Lake Eyre similar to the New Red Sandstone beds of Devon, but the shrinking of Lake Eyre to its present dimensions and desiccated state may have had its counterpart in those earlier times. When the sea or lake reached its westward limit the climate may have changed, as it did in Australia, and have become arid. The water might retreat through desiccation, or owing to silting up, or owing to a relative rise in the land, or a combination of these causes. Before desiccation became severe, however, the marine conditions of Rhaetic times supervened.

The preservation of footprints in the sandstone at Poltimore, north-east of Exeter, does not conflict with the conditions sketched above. On a tideless shore, such as one would expect with an enclosed body of water, sand wetted by rain and then covered by blown sand or dust might preserve them.

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EXPLANATION OF PLATES

PLATE XVIII

FIG. 1.—A section on The Parson and Clerk headland photographed at low tide.

FIG. 2.—A fallen block on Watcombe Beach, showing cobbles on a bedding-plane.

FIG. 3.—Fallen blocks on Watcombe Beach, showing cobbles and bedding.
In Fig. 2 the camera case is 8 inches across the top. The scale for Fig. 3 is the same.

PLATE XIX

FIG. 1.—A section on Maidencombe Beach showing some resemblance to raised beaches of Devon and Cornwall. Compare Plate V, A, and Plate VII, A, in the revised Torquay Memoir, Sheet 350, 1933. The camera case at the bottom of the photograph measures 8 inches across the top.

FIG. 2.—A section near Bundle Head showing the white beds. Above the cross is a 2 ft. rule opened as a V each limb being 1 foot. To the left of the rule are four joint-fissures.

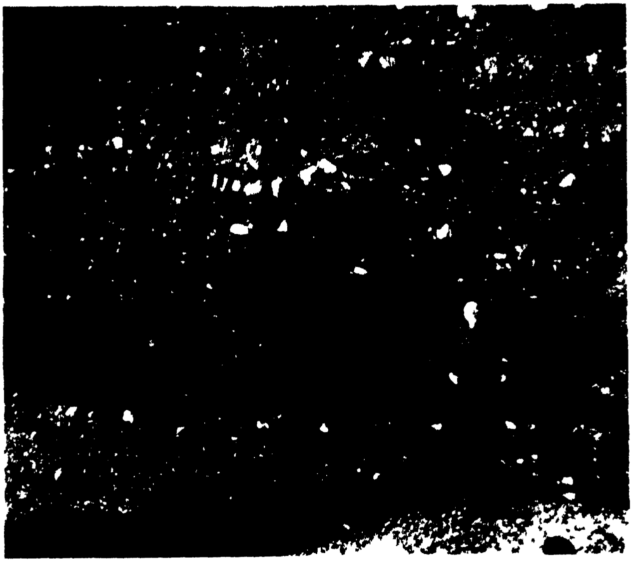

Fig. 2

Fig. 3

Typical Stony Beds of the New Red Sandstone, South Devonshire

FIG. 1

FIG. 2

NEW RED SANDSTONE, SOUTH DEVONSHIRE

On the so-called Metamorphism of the Trias in the Alps

By O. T. Jones

AMONG a batch of reprints recently received from Professor Lugeon (1946) is one dealing with the above subject; it is of more than local interest as it prompts comparison with certain phenomena in this country.

Any British geologist who like myself has visited the Swiss Alps around the borders of the northern massif of the Aar, or the Aiguilles-Rouges and seen the basal beds of the Trias where that formation rests on the gneiss, schists, or granites has had no difficulty in recognizing at that horizon one of the major unconformities of the geological column. Nor until recently had any other geologist.

A British geologist would recall the incontestably unconformable relations of the New Red Sandstone, mainly Trias, but in some cases Permian, to the older rocks ranging from Coal Measures downwards which is one of the most obvious features of the geological map of Britain, but the resemblance evidently goes further.

A few years ago Lugeon (1916) described and discussed the origin of a red staining which affects the schists of the Aiguilles-Rouges near their contact with the base of the Trias. The staining is sometimes rose-coloured, sometimes almost carmine and penetrates in places to a depth of some 40 metres into the crystalline rocks. Such colouration does not occur everywhere below the Trias but is frequent. It is explained as a product of the ancient weathering of the Hercynian peneplain which is exposed in the cores of the northern massifs and is not a part of the Trias formation. In places these subaerial mantle deposits were removed by the advancing Triassic sea leaving a well-washed floor of unaltered crystalline rocks, but in other places where pre-Triassic erosion did not bite so deeply into the surface only a small thickness of stained crystallines remains to attest the near presence of the old peneplain surface and the former conditions of weathering.

Lugeon suggests that the original colour was probably ochreous, but that under the enormous load of sediments which between the Trias and the Tertiary periods buried the rocks of the peneplain the iron salts responsible for the staining were dehydrated so that the pigmentation is now due to haematite in company with some magnetite.

I have noticed in many places reddening of various rocks, more particularly in association with Triassic rocks, but the phenomenon is probably not confined to their neighbourhood. Strahan (1899) called attention to it in the Vale of Glamorgan where the Keuper is well-developed. He attributed the effect to iron salts carried down from the Trias and concluded that where such staining is found Trias had

formerly occurred above that place. This view was accepted by Sibly (1927) for the origin of the iron ores of the Forest of Dean and South Wales. Since all the rocks from the Silurian to the Coal Measures are affected in varying degrees and some of the places are far removed from the existing Trias as well as some distance above the level of the base it seemed to follow that the Trias once spread far beyond its present outcrop. Some time afterwards (1930) I gave reasons for dissenting from that view and attributed the reddening to weathering of the pre-Triassic surface under continental conditions.

I have seen similar effects in many parts of Britain, but it is only necessary to refer to a few examples. In the Ingleton coalfield the Four-Foot seam is not far below the unconformable base of the New Red Sandstone. As the workings approached nearer to the contact the coal became so reddened that it was unsaleable and small clay-ironstone nodules were converted into bright red haematite. It can be seen in places in the Ludlow rocks of East Denbighshire, not many miles from the Triassic rocks of the Vale of Clwyd. Farther south the Upper Ordovician rocks are affected near Welshpool, while between that place and Oswestry the Carboniferous Limestone of Llanymynech is strongly ferruginized. The Trias occurs not far away in both cases. There are places in the Lake District where similar staining can be seen: so far as I know these lie on the great north-south shatter belts and there is no proof that it has anything to do with Trias deposits. In the River Rawthey, east of Sedbergh, Silurian slaty rocks are strongly reddened from the valley floor to the high level surface near Cautley Spout. In this area Red Beds lying at the base of the Carboniferous are well developed and the reddening may be associated with them, either directly or indirectly.

Staining of the shales and greywackes is conspicuous near Beattock Summit some miles above the New Red rocks of Dumfries, etc., while the highest level at which I have observed it in Scotland is at the crest of the Moffat road above the Devils Beef-tub. Here both shales and greywackes are affected and it is noteworthy that the shales are not even cleaved.

At the extreme north of Scotland the Moine gneiss is strongly reddened on the surface and on joints. I observed it by the side of the road east of Loch Eriboll, where the surface forms part of a rather even peneplain which extends from the coast for many miles to the south.

Apart from the last example no geologist would dream of attributing the effects which I have noted above and many others like them to metamorphism for the sufficient reason that neither the rocks themselves nor others which underlie them for thousands of feet show any metamorphic effects.

Some of the contacts where this phenomenon occurs in the Alps have been famous since the early days of Alpine geology; among them is the section at Scheidnössli, near Erstfeld, in the canton of Uri (for references see Lugeon, 1946). There the crystalline massif of the Aar plunges beneath the enormous thickness of the remains of the autochthonous cover of this part of the Alps and of the nappes piled up above it. Another section to which attention has been directed in more recent years was exposed in the cutting of the Loetschberg tunnel, but similar ones can also be seen near by, as at the Col du Loetschberg, and Arpeligrat, all near the contact of the Trias with the Gastern gneiss or granite massif.

The Scheidnössli section was described by W. Staub (1911) who examined it in 1909 in company with Émile Argand and B. G. Escher. The middle Trias consists of a great thickness of dolomitic limestone, but the lower Trias is only some 5·1 metres of alternating beds of dolomite, shale, and quartzite. The latter was recognized as the basal quartzite which is the form the lowest beds of the Trias usually exhibit. Between the well-bedded Trias and the subjacent gneiss there is an intercalation about 3·7 m. in thickness of a peculiar kind of arkose which is affected by a cleavage like that of the underlying gneiss, but which is wholly absent from the Trias; it also shows a concertina-like puckering with some orientation of the particles such as one sometimes sees as the result of solifluction. The arkose grades downwards into the gneiss, but upwards it is sharply truncated by the base of the Trias. The rock is normally yellow, but is in places green due to chloritized biotite; it contains rounded grains of quartz and cannot possibly be attributed to a mechanical origin such as thrusting. Staub entertained no doubt that this arkose was a material which had been "disintegrated *in situ*".

With this conclusion Lugeon agrees and in the light of his own wide experience adds that it was an ancient weathering product consisting of sand and clay which was formed on the peneplain surface and was subsequently cemented and lithified.

De Fellenberg (1893) described a similar deposit at Arpeligrat and at the Col du Loetschberg as an arkose or residual sandstone and regarded it as a detritus produced from the subjacent Gastern gneiss or rather granite. Green or violet conglomerates yielded some pebbles of that granite and he remarked that in places the deposit resembled a gneiss and in other places it was difficult to tell whether it was a clastic rock or a part of the crystalline below. Another observer Turnau (1906) claimed to have discovered in it aplitic veins derived from the granite below and as de Fellenberg had attributed the rock to the Verrucano (commonly regarded as Permian) he concluded that the veins were of Permian age. Undoubted Permian is well known in

the Aiguilles-Rouges and elsewhere in the form of conglomerates or purple sandstones and together with the Carboniferous forms a part of the unconformable cover of the crystallines. Apropos of this Lugeon remarks that never have apophyses of any crystalline rock been seen to cut either the Carboniferous or the Permian of those areas.

Truniger (1911) found that although these ill-defined veins did exist and passed downwards into the crystallines the deposits could not be regarded as Permian. They are described as green, brown, or rusty schist-like rocks which passed gradually down into the granite or other crystalline rock. They contained grains of quartz and sericitized felspar in a sericitic cement, and all the accessory minerals of the granite were more or less represented, but pyrite was much more abundant.

Lugeon concludes from these and other investigations that these peculiar rocks which occur here and there below the base of the Trias are mantle rocks formed by decomposition of the old rocks of the peneplain and remarks that among Swiss geologists the question was finally settled.

However it was reopened in an unexpected quarter. R. Perrin (1935) claimed that the discordant superposition of a sedimentary rock on a crystalline rock which is folded proves only that the underlying rock has been formed and folded before the deposition of the unconformable deposit ; but he adds evidently as a hint of things to come that certain rocks act as a barrier against the propagation of metamorphism from below. Accordingly R. Perrin and M. Roubault (1941) declared that the Trias seemed to them to have played that part very effectively in certain parts of the Alps. This, as Lugeon notes in spite of the fact that the basal quartzite of the Trias which serves as the barrier is, in places, no more than 1 metre in thickness. These authors thus regard these peculiar rocks as a product of post-Triassic metamorphism which is also presumably responsible for the production of the schists and gneisses below. This work has previously been noticed, apparently with approval, by Doris Reynolds, in the *Geological Magazine* (1947, p. 106). As Michel Levy (1892) once aptly commented in reference to another occurrence at Prarion it would be difficult to admit that in a concordant series the lower beds had been felspathized and transformed into a gneiss while at a few metres above the strata remained in the condition of unaltered sandstone.

Lugeon refers to many other sections which show similar phenomena in the few metres that intervene between the undoubted base of the Trias and the crystallines. In some cases they contain jaspers, in others dolomitic nodules where the overlying Trias consists mainly of dolomite, and of gypsum where the Trias contains much anhydrite.

Clearly the mineral matters of the nodules have been carried by descending waters.

I recall very clearly an occasion in 1924 when a young American petrologist tried to convince me that the individual boulders in a conspicuous conglomerate near the Hollinger mine in Northern Ontario had been made over from individual pillows in the Keewatin pillow-lavas. To the obvious objection that I raised as to the vast removal of iron, lime, and magnesia that the process involved he replied that the lime and magnesia had gone to form the great Pre-cambrian dolomite masses while the iron gave the well-known iron-ores of the Canadian Shield !

It seems I was wrong in thinking as I did then that folly could no higher go, for here we have a case of investigators claiming to prove from the examination of some thin slices of rocks that one of the best established unconformities in Europe is nothing but a delusion of which a great number of geologists whose names are known wherever geology is taught have one and all become the victims.

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For other references, see Lugeon (1946).

Sowerby's and Sharpe's *Belemnites lanceolatus* and their relation to *Belemnites lanceolatus* Schlotheim, 1813

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(PLATE XX)

BELEMNITES are common throughout the boreal province of the Upper Cretaceous Series of Eurasia occurring at practically all horizons of the so-called Senonian stage (in the broader sense) nearly everywhere in this province ; often they are the only group of fossils to be met frequently enough to be used for stratigraphical purposes. Despite this there have so far been relatively few efforts to use the Upper Cretaceous belemnites as zone-fossils, with the exception of some *Actinocamax* and *Gonioteuthis* species. The probable reasons for this regrettable neglect have already been mentioned in a previous paper (e.g. Jeletzky, 1946, pp. 87-90). Our researches, the results of which have till now only partly been published (e.g. Jeletzky, 1940, 1941, 1946) have shown that the Upper Cretaceous belemnites occur relatively frequently, and in the same stratigraphical order throughout the whole Eurasian boreal province and are in fact excellent guide fossils.

The present paper is an attempt to determine the taxonomic relations between *Belemnites lanceolatus* Schlotheim, 1813 ; *Belemnites lanceolatus* Sowerby, 1829, and *Belemnites lanceolatus* Sharpe, 1853–7 ; to establish valid names for the two last-named, undoubtedly different, species ; and to investigate their taxonomic positions within the family Belemnitellidae Pavlow, their geographical distribution and their stratigraphical value.

Sowerby (1829, p. 208, tab. 600, figs. 8–9) described two belemnoid guards from the Cenomanian of England (Hamsey) as *Belemnites lanceolatus*, probably considering them to be identical with the earlier described *B. lanceolatus* Schlotheim, which is certainly incorrect. The name *Belemnites lanceolatus*, Schlotheim, 1813, has been frequently applied to Jurassic and Lower Cretaceous belemnoid species (e.g. *Hibolites hastatus* Blainville, 1827) or regarded as a synonym of *Belemnites mucronatus* Schlotheim, 1813, and was a real stumbling block in belemnoid taxonomy for more than a century. Since Schlotheim (1813, p. 111) has named *Belemnites* sp. 2° of Breynius (1732, tab. Belemnites, fig. 7*a*) as holotype of his species, the whole question depends on the nature of this specimen.

There can be little doubt that the above-mentioned and other specimens of *Belemnites* sp. 2° of Breynius (1732, pp. 45–6, figs. 7–14 *non* fig. 15) belong to a Belemnitella-like species of the family Belemnitellidae Pavlow, since they all show the true ventral alveolar fissure

starting at the very apex of the alveolar cavity, and the reduced alveolar angle. This Belemnitella-like form differs both morphologically and phylogenetically from all other hitherto-known Belemnitella-like species (e.g. *B. mucronatus* Schloth.) and is an excellent guide fossil of the Lower Maastrichtian (= Lanceolata Strata) of Russia, Poland, North-Western Europe, and possibly Great Britain too (cf. p. 344). Following the investigations of Nowak (1913, pp. 403–7, taf. xlii, figs. 19, 20, 23, 24 ; taf. xliii, figs. 36*b*, *c*) and Jeletzky (1941, pp. 28–30, fig. 2) *B. lanceolatus* Schlotheim must be regarded as a genotype of the distinct genus *Belemnella* (Nowak). A typical representative of *Belemnella lanceolata* (Schlotheim) Nowak, 1913, is shown on Plate XX, figs. 1*a*, *b*.

The Cenomanian specimens of Sowerby are, on the contrary, typical representatives of the genus *Actinocamax* Miller, 1826, *s.str.*, and have nothing in common with any Belemnitella-like species. Nevertheless they have been often mistaken for *Belemnella lanceolata* (Schloth.). Bülow-Trummer (1920, p. 196), for example, wrongly refers *A. lanceolatus* of Stolley (1905, p. 7) and *B. lanceolatus* of Fritsch (1872) to the above-mentioned Belemnitella-like species.

Sowerby (1829, p. 208) considered his *B. lanceolatus* to be different from *Belemnites plenus* Blainville, 1827 ; he points out that it is a " much more elongated shell than *B. plenus*, which it much resembles ". Later many well-known authors (e.g. Sharpe, 1853–7 ; Schlüter, 1876) have regarded *B. lanceolatus* Sowerby *non* Schlotheim as synonymous with *B. plenus* Blv. ; others (e.g. Jukes-Browne and Hill, 1896 ; Jukes-Browne, 1900–4, vol. ii ; Crick, 1910, pp. 363, 365) have maintained the opinion of Sowerby, while Stolley (1905, pp. 7–9 et seq.) has concluded that *B. lanceolatus* Sowerby must be regarded as a distinct *Actinocamax* species ancestral to *A. plenus* Blv. ; his opinion was supported by many other German, Czechoslovakian, and Scandinavian authors. In France also opinion is strongly divided on this subject.

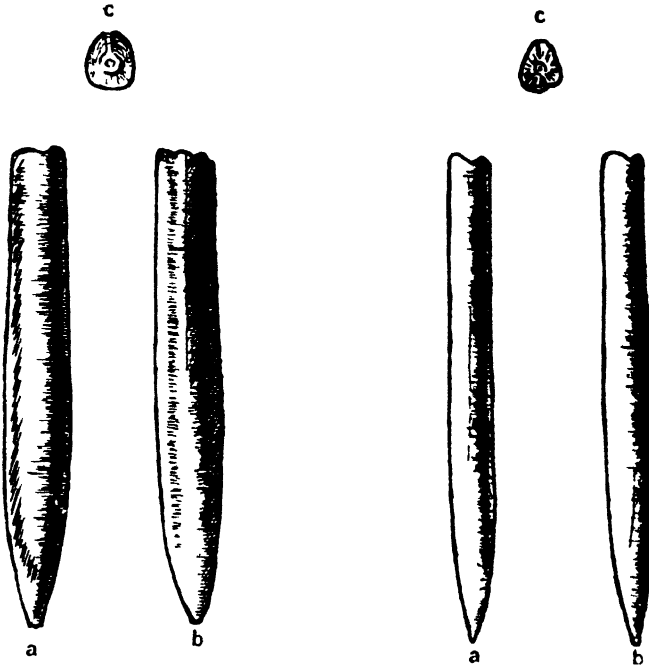
All those authors who maintain the independence of this controversial *Actinocamax*-form retain for it the illegitimate name *Belemnites lanceolatus* Sowerby *non* Schlotheim. This taxonomic mistake still remains uncorrected.

Arkhangelsky (1912, p. 578, tab. x, figs. 1–5) has described *B. lanceolatus* Sowerby *non* Schlotheim from Cenomanian beds of Eastern Russia under the new name *Actinocamax primus*. Since the name *B. lanceolatus* Sowerby, 1829, is invalid and can never be used, the name *Actinocamax primus* Arkhangelsky, 1912, is the only valid name for this form should its independence from *A. plenus* Blv. be upheld.

Like Sowerby, Jukes-Browne and Hill, Crick, Jukes-Browne, Stolley, Arkhangelsky, and many others, we are inclined to consider *A. primus* Arkh. to be a different species from *A. plenus* Blv. This conclusion is

based on the presence of some quite stable morphological distinctions between them and on their different stratigraphical occurrence.

So far as the morphology of guards is concerned, *A. primus* Arkh. is always much more slender than *A. plenus* Blv. Typical repre-



1. 2.

Text-fig. 1.—*Actinocamax primus* Arkhangelsky. Natural size. *a*, Ventral aspect ; *b*, lateral aspect ; *c*, view of alveolar end. Cenomanian : lower zone with *Schloenbachia varians* Sowerby represented by glauconite sands with phosphorite nodules ; north-western border of the Donetz Basin ; Woroshilowgrad province ; "Belaya Gora" quarry, near the town Lissitchansk. All figured specimens are in the Palaeontological Museum of the Geological Survey of Canada, Ottawa.

Text-fig. 2.—*Actinocamax primus* var. *elongata* Arkhangelsky. Natural size. *a*, ventral aspect ; *b*, lateral aspect ; *c*, view of the alveolar end. Same horizon and locality as the previous specimen (Text-fig. 1).

sentatives (*A. primus* var. *elongata* Arkhangelsky) are also relatively more elongated than *A. plenus* (cf. Sowerby, 1829, tab. 600, fig. 8 ; this paper Text-fig. 2). In Russian specimens the average size remains well below the average size of *A. plenus* and guards of *A. primus*

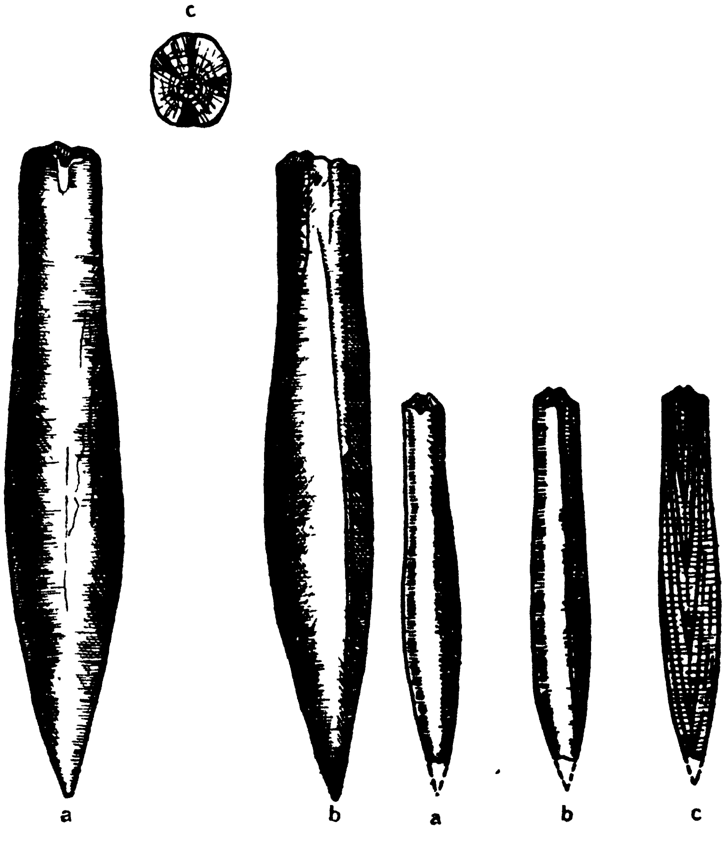
are always almost cylindrical throughout their length and never become so conspicuously swollen in their posterior part as those of typical representatives of *A. plenus*. The apical point of the guard is situated centrally in *A. primus*, but it is clearly displaced towards the dorsal side of the guard in *A. plenus*. All above-mentioned differences are well displayed by Text-figs. 1, 2, 3, 4, showing typical representatives of both species.

It is obvious that *A. primus* and *A. plenus* characterize quite different zones of the Upper Cretaceous Series everywhere they have so far been found. In Great Britain, as suggested by Jukes-Brown and Hill (1896, pp. 111, 116, 163), Jukes-Browne (1900–4, vol. ii, pp. 21, 26), and Crick (1910, pp. 363–5), *A. primus* occurs exclusively in older Cenomanian rocks in the zone of *Schloenbachia varians* Sowerby and at the base of the zone of *Holaster subglobosus* Leske (= local zone of *Offaster sphericus* Schlüter). *A. plenus* is on the contrary restricted to the zone of *Holaster subglobosus* Leske ; it is to be often met only in its upper part (= Belemnite Marls), which is commonly named the subzone of *A. plenus*. Jukes-Browne (1900–4, vol. ii, p. 21) points out that the highest bed of the zone of *H. subglobosus* Leske (= Belemnite Marls) is characterized by the frequent occurrence of *A. plenus* and that the fossils of that bed " are a mixture of Lower and Middle Chalk species, making it evident that the deposits were formed during an epoch of transition from one set to another ". Therefore the Belemnite Marls of Great Britain (= zone of *A. plenus*) can under no circumstances be older than the uppermost Cenomanian and may include the lowermost Turonian also. *A. plenus* is unknown in the overlying undoubted Turonian rocks of Great Britain (= zone of *Inoceramus labiatus* Schloth.).

The distribution of these belemnoid species in Russian sections coincides completely with that in Great Britain, with the exception that *A. plenus* extends into the Lower Turonian strata (= zone of *I. labiatus* Schloth.) in Russia and even seems to abound there at some localities.

In the Cenomanian of the north-eastern slope of the Dniepr-Donetz Basin, Kanev, Podolia, and the north-western borderland of the Donetz Basin, all investigators have found typical *A. plenus* (cf. Text-figs. 3, 4) in the uppermost Cenomanian beds only. This horizon is represented everywhere by marls or by glauconitic sandy chalk. In Podolia (Kamenetz and Mogilev provinces) it contains *H. subglobosus* Leske, *Acanthoceras rothomagense* d'Orbigny and other index fossils of the Upper Cenomanian. It seems quite probable that in some localities (e.g. Kanev) the lower part of this horizon contains also transitional forms between *A. primus* and *A. plenus* (cf. Jeletzky, 1946, p. 101, fig. 4), but this cannot yet be stated definitely.

The underlying relatively thick series (up to 40–50 m.) of glauconite sands with phosphorite nodules and bands of sandstone (in Podolia represented in places by marls) on the contrary contains *A. primus* and



3. 4.

TEXT-FIG 3.—*Actinocamax plenus* Blainville. Natural size. Fully grown, typical specimen : *a*, ventral aspect ; *b*, lateral aspect ; *c*, view of alveolar end. Cenomanian ; upper zone with *Acanthoceras rhotomagense* d'Orbigny represented by marls ; Podolia, village Osarintsi.

TEXT-FIG. 4.—*Actinocamax plenus* Blainville. Natural size. Young specimen : *a*, ventral aspect ; *b*, lateral aspect. It is remarkable that even this relatively young specimen shows all essential morphological characters of the fully-grown ones (cf. Text-fig. 3) ; *c*, ventral aspect ; a polished longitudinal plate showing the growth-stages of the guard. It may be seen that the shape of the youngest stages visible on the section closely resembles the shape of the full-grown guard of *A. primus* (cf. Text-figs. 1, 2). The typical shape of *A. plenus* Blv. appears only on the later stages. Same horizon and locality as the previous specimen (Text-fig. 3).

its varieties exclusively (cf. Text-figs. 1, 2). In the north-western border of the Donetz basin (" Belaya Gora " quarry) it has, however, yielded also *Schloenbachia varians* Sowerby.

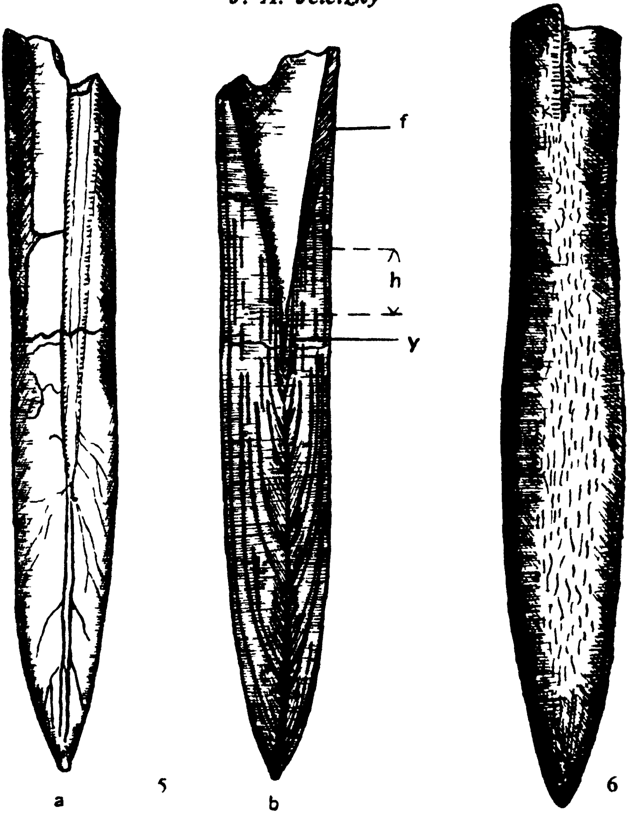
In Germany, Czechoslovakia, and France (e.g. Stolley, 1905 ; Schlüter, 1876 ; Fritsch, 1872) the vertical distribution of *A. primus* and *A. plenus* seems to coincide completely with that in Russia. As shown by Schlüter, Stolley, and other authors, *A. plenus* passes up into Lower Turonian rocks (= zone of *I. labiatus* Schloth.) in these countries also.

In these circumstances the presence of numerous transitional forms linking the two species is quite natural and does not preclude their distinction. In our opinion *A. primus* is ancestral to *A. plenus* and the ontogenetic development of *A. plenus*, as shown by Jeletzky (1946, p. 100, fig. 2*a*), and in Text-fig. 4*c* of this paper, supplies additional proof. Further investigations will probably reveal a continuous suite of transitional forms.

It should be mentioned that the bigger of two specimens of Sowerby (1829, tab. 600, fig. 9), the specimen of Fritsch (1872, tab. xi, figs. 6, 7) and possibly also the biggest one of Arkhangelsky (1912, tab. x, figs. 4–5) seem to represent such transitional forms. Fritsch's specimen, together with *Actinocamax* aff. *plenus* Blv. of Jeletzky (1946, p. 101, fig. 4) may belong to a new variety of *A. plenus* or even be a new species. Anyway, all these specimens are far above the average size of *A. primus* so far as Russian representatives are concerned and show distinct morphological features. Therefore we have chosen the smaller specimen of Sowerby (1829, tab. 600, fig. 8) as type-specimen (holotype) of *A. primus*.

Sharpe (1853–7, p. 7, tab. i, figs. 4–6) has applied the name *Belemnites lanceolatus* to the Belemnitella-like form from the Upper Chalk of England, evidently considering it to be identical with Schlotheim's species (1813, p. 111 ; 1820, p. 49). The name *B. lanceolatus* Sharpe, 1853–7, has frequently been used since by many other British authors for this Belemnitella-like British form (e.g. Blackmore, 1896, p. 529, tab. xvi, fig. 1 ; Jukes-Browne, 1900–4, vol. iii, p. 11 ; Crick, 1910, p. 365).

The specimen of Sharpe (1853–7) and those of other British authors above mentioned have certainly nothing in common with *Belemnella lanceolata* (Schloth.) and are on the contrary very similar to, but not identical with, *Belemnitella mucronata* (Schlotheim, 1813) d'Orbigny, 1842. The dorso-lateral grooves and main vascular imprints of *B. lanceolatus* Sharpe, *non* Schlotheim, resemble those of *B. mucronata* (Schloth.) and differ considerably from those of *Belemnella lanceolata* (Schlotheim) (cf. Nowak, 1913, pp. 403–7, taf. xliii, figs. 36*b*, *c*, *d*, and Pl. XX, figs. 1*a*, 2*a*, and Text-fig. 5*a* of this paper). The same applies to the



TEXT-FIG. 5.—*Belemnitella praecursor* Stolley. Natural size. *a*, lateral aspect, showing a specimen somewhat different from the type-specimen of Stolley (1897), since it exhibits very feeble dorso-lateral grooves, lateral grooves, and main vascular imprints. It may be seen that their character is quite similar to those of *B. mucronata* shown on Pl. XX, fig. 2*a* ; *b*, lateral aspect ; a polished longitudinal plate prepared from the same specimen showing the growth-stages of the guard and other internal morphological features. It may be seen that all morphological characters above mentioned (cf. Pl. XX, figs. 1*b*, 2*b*) coincide completely with those of *B. mucronata* (Schloth.), but are quite different from those of *Belemnella lanceolata* (Schloth.). Lettering as on Plate. Uppermost Santonian or lowermost Lower Campanian (grey marls with *G. granulata* Blv., *A. verus* var. *fragilis* Arkh., *Pteria tenuicostata* Röm., etc.) ; north-eastern slope of the Dniepr-Donetz Basin ; Tshernigov province ; right shore of the Desna River 0 5 km. south of Pushkari.

TEXT-FIG. 6.—*Belemnitella praecursor* Stolley. Natural size. Ventral aspect The specimen shows no vascular imprints ; only feeble dorso-lateral and lateral grooves and feeble longitudinal striae are visible on the surface of the guard. Uppermost Santonian or lowermost Lower Campanian (grey marls with *G. granulata* Blv., *G. granulato-quadrata* Stoll., *A. verus* var. *fragilis* Arkh., etc.) ; north-western border of the Donetz Basin ; Stalino province ; near Mayaki, on the Donetz River.

angle of the alveolar cavity and other internal morphological characters (cf. Jeletzky, 1941, pp. 28–30, figs. 1, 2, and Pl. XX, figs. 1*b*, 2*b*, and Text-fig. 5*b* of this paper). Moreover the investigations of Blackmore (1896) and Jukes-Browne (1900–4, vol. iii) have proved undoubtedly that the stratigraphical horizon of *B. lanceolatus* Sharpe *non* Schlotheim is quite different from that of *Belemnella lanceolata* (Schloth.); it characterizes the lowest horizon of Lower Campanian strata (= British zone of *B. quadrata* Blv.) of Great Britain and is accompanied there by *Gonioteuthis quadrata* (Blainville, 1827) Bayle, 1878. *Belemnites lanceolatus* Sharpe *non* Schlotheim therefore belongs to the genus *Belemnitella* d'Orbigny, 1842, emend Jeletzky, 1941, and has nothing in common with *Belemnella lanceolata* (Schloth.).[1] The name *B. lanceolatus* Sharpe, 1853–7, is thus another homonym of *B. lanceolatus* Schlotheim, 1813. Happily there is no need to give a new name to this form, since it has already been described by Stolley (1897, p. 297, taf. iii, fig. 24) as *Belemnitella praecursor* from the Upper Granulata Chalk (= lowest horizon of Lower Campanian) of North-Western Germany, which name is thus valid for *B. lanceolatus* Sharpe *non* Schlotheim. *Belemnitella praecursor* Stolley, 1897, has later been described from the apparent equivalents of the lowest zone of Lower Campanian of Eastern Russia by Arkhangelsky (1912, p. 604, tab. ix, figs. 1–2), who has already recognized the identity of *B. praecursor* Stolley with *B. lanceolatus* Sharpe *non* Schlotheim. Moreover as *B. praecursor* has been described from further localities in Russia, Scandinavian countries, and North-Western Germany, always from the equivalents of the lowest Lower Campanian or the uppermost Santonian (exact correlation is not yet always possible), it can be regarded as the index fossil of a relatively thin zone of that age throughout the boreal province of Eurasia.

Hägg (1947, p. 98) has recently described under the name *Belemnitella lanceolata* (Schloth.) not only the true *Belemnella lanceolata* (Schloth.), but also *Belemnitella praecursor* Stolley and still other Belemnitella-like forms, to judge by the authors and localities he mentions, and particularly from the stratigraphical range given for this species, from the Emscher stage (= Coniacien) to the Constrictus zone (= ? Lower Maastrichtian).

Many authors (e.g. Schloenbach, 1868, p. 461; Schlüter, 1876;

[1] Jukes-Brown (1900–4, vol. iii, p. 12) mentions the frequent presence of *B. lanceolata* in the zone of *B. mucronata* in Dorset and the Isle of Wight. This remark cannot in any case refer to *B. lanceolata* Sharpe *non* Schlotheim, which characterizes exclusively a much older horizon. Therefore it is quite probable that in this case the true *Belemnella lanceolata* (Schloth.) is meant. This cannot be stated definitely yet, since some Upper Campanian Belemnitellas closely related to *B. mucronata* (Schloth.) can be very similar to *Belemnella lanceolata* (Schloth.) in the form of their guards.

Moberg, 1885, p. 61 ; 1894, p. 74) consider *B. lanceolatus* Sharpe *non* Schlotheim to be only a variant of *B. mucronata* (Schloth.), which is certainly wrong. To begin with, *B. praecursor* Stolley differs from *B. mucronata* (Schloth.) mut. *senior* Nowak, 1913, which must be regarded as a typical form of this species (cf. Breynius, 1732, pp. 44–5, figs. 1, 6 ; Nowak, 1913, pp. 395–8, taf. xlii, fig. 22 ; this paper, Pl. XX, fig. 2), by the much shorter fissure, shallower alveolar cavity, and the complete absence or extreme weakness of the dorso-lateral grooves, lateral grooves, and vascular imprints, together with the absence of a well-formed " mucro " on the apical end of the guard. The guard itself is much more slender than that of *B. mucronata* mut. *senior* (cf. Stolley, 1897, p. 297, taf. iii, fig. 24 ; Müller and Wolleman, 1906, tab. vi, figs. 7, 8, and Text-figs. 5 and 6 of this paper). It should be mentioned, however, that together with above-mentioned British authors and Arkhangelsky, we also refer to *B. praecursor* Stolley (= *B. lanceolatus* Sharpe) specimens showing extremely feeble vascular imprints as well as dorso-lateral and lateral grooves if they agree in all other respects with the diagnosis given above (cf. Text-fig. 5) ; and we reject the contrary views of Stolley (1897) on this point. *B. mucronata* (Schloth.) mut. *senior* Nowak and the other forms of this species (mut. *junior* Nowak *s.str.*), which are so frequent in the Upper Campanian and even in the upper beds of the Lower Campanian together with *Gon. quadrata* Blv., have never yet been found so far down as the lowest horizon of the Lower Campanian. *Belemnitella mucronata* (Schloth.) mut. *anterieur* Stolley, 1897, which is recorded from the lowest Lower Campanian as well as Upper and even Middle Santonian strata (Sweden, North-Western Germany, Russia), differs considerably from *B. mucronata* mut. *senior* as well as from *B. praecursor* Stolley and is possibly a distinct species, maybe an immediate predecessor of *B. mucronata* mut. *senior.* It is uncertain whether *B. praecursor* is ancestral to *B. mucronata* mut. *senior* or any other form of this species ; it is possibly an offshoot from the common root (*B. mucronata* mut. *anterieur* or some still older Belemnitella-like form).

We have no doubt that further revision of the Upper Cretaceous Belemnites of Great Britain and especially comparison with the forms of North-Western Europe, Poland, and Russia would reveal many interesting morphological, phylogenetic, and stratigraphical results, possibly with further taxonomic confusion. We have no doubt, too, that any such revision would reveal a close resemblance between the British Upper Cretaceous belemnoid faunas and those of the above-mentioned European and Eurasian countries, and thus allow a much more exact correlation of the Upper Cretaceous deposits than is now possible.

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EXPLANATION OF PLATE XX

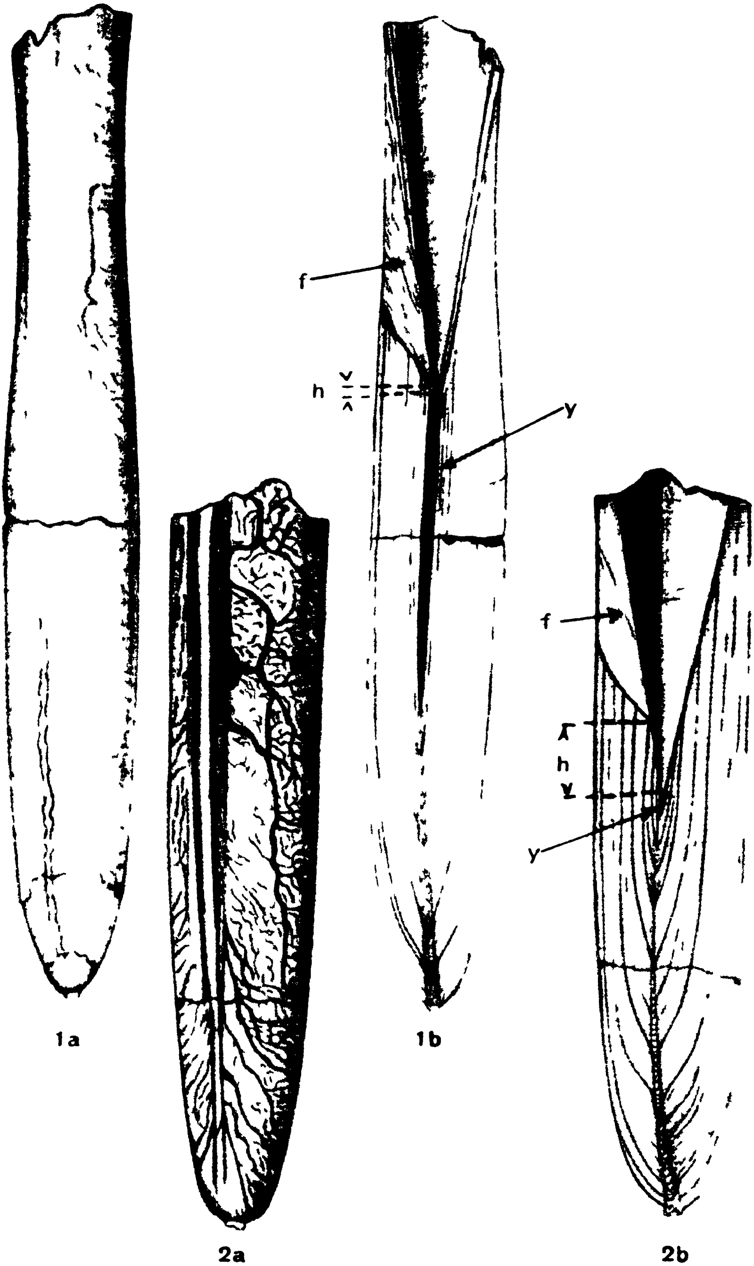
FIG. 1.—*Belemnella lanceolata* (Schloth.). Natural size. Fully grown, typical specimen.

1*a*, lateral aspect, showing the wave-like curvature of dorso-lateral grooves in their posterior third ; the angle between them and main vascular branches is always more than 30° ; 1*b*, lateral aspect ; a polished longitudinal plate prepared from the specimen represented in fig. 1*a*, showing the growth-stages of the guard and other internal morphological features. The needle-like character of the earliest growth-stages of the guard (this "needle" extends to 2/7–2/3 the length of the full-grown guard), the reduced angle of the alveolar cavity (= 13–17°), the extremely small interval between the protoconch and the beginning of the ventral fissure on the inner wall of the alveolar cavity (0·5–2·5 mm.) and the distinct character (fig. 1*a*) of the dorso-lateral grooves and main vascular imprints distinguish this species from all other Belemnitella-like species, however similar in the form of the guard. y = earliest growth-stage (needle-like) visible on the section ; h = interval between the protoconch and the beginning of the ventral fissure on the inner wall of the alveolar cavity ; f = ventral fissure. Lower Maastrichtian (= Lanceolata Strata) ; north-eastern slope of Dniepr-Donetz Basin ; Sumy province ; village Vasilieva on the Psiol River. Author's collection.

FIG. 2.—*Belemnitella mucronata* (Schloth.) mut. *senior* Nowak. Natural size. Fully grown, typical specimen.

2*a*, lateral aspect. In contrast to *Belemnella lanceolata* (Schloth.) (fig. 1*a*) the dorso-lateral grooves are quite straight in their posterior third and the main vascular imprints branch out at an angle always less than 30° ; 2*b*, lateral aspect ; a polished longitudinal plate prepared from the specimen represented in fig. 2*a*, showing the growth-stages of the guard and other internal morphological features. In contrast to *Belemnella lanceolata* (Schloth.) the earliest growth-stages visible on the section are very short, small, nail-like, and do not differ greatly from the full-grown guard in their shape. The angle of the alveolar cavity (20–22°) and the interval between the protoconch and the beginning of the ventral fissure on the inner wall of the alveolar cavity (6–10 mm.) are much greater than those of *Belemnella lanceolata* (Schloth.). Upper Campanian (= Mucronata Strata) ; north-western border of Donetz Basin ; Woroshilowgrad province ; near the village Belogorovka near the town Lissitchansk. Author's collection. Lettering as in Fig. 1*b*.

Originals in the Palaeontological Museum of Geological Survey of Canada, Ottawa.



CRETACEOUS BELEMNITES.

On Magma-Types and their Nomenclature

By M. K. WELLS and A. K. WELLS, University of London

IN the discussion on a paper read recently by A. G. MacGregor on Scottish Carboniferous volcanicity,[1] one of us, speaking on behalf of both, raised some points concerning the nomenclature of magma-types which we feel are worth amplifying. The points at issue concern firstly the use of the terms " tholeiite " and " olivine-basalt " when applied to fundamental magmas, and secondly the propriety of referring to the suites of rock-types supposed to be derived from them as " calc-alkali " and " alkali " respectively.

A " magma type " was first given precise definition by the authors of the Mull Memoir,[2] in which they state that : " The conception of magma-type is based upon composition alone. In this it differs from the conception of rock-type which takes into account texture as well as composition." It is obvious from the number of magma-types named in this memoir that only a limited range of composition is envisaged ; and that, in fact, a magma-type so defined was meant to be only a little different from a " rock-magma ", or melt from which a specific rock-type has crystallized. This difference is expressed in the fact that a magma-type represents " an average composition around which actual rocks seem to group themselves ".

There is no doubt that this is a very useful concept. It links up rocks of diverse character which yet possess sufficient chemical similarity to justify the assumption of their derivation from a common source. Obviously different physical conditions obtaining during crystallization may produce a wide variation of rock-types from one magma-type, depending upon the mode of occurrence of the resulting rock masses, and upon the accidents of cooling history, such as the retention or loss of fugitive constituents.

In the past, two criteria have been used for assigning rocks to a particular magma-type and these have resulted in two different methods of naming the latter : firstly, chemical composition, and secondly, mineral content and texture of the rocks concerned. We suggest that there is a third alternative which appears to be more appropriate when dealing with magma-types of world-wide significance, such as those of basaltic composition, in which case the magma-type may be named according to its inferred relationship to a particular crustal layer.

[1] Abstract in *Proc. Geol. Soc. London*, No. 1441, May, 1948, p. 72.
[2] Tertiary and post-Tertiary geology of Mull, *Mem. Geol. Surv.*, Scotland, 1924, p. 13.

(1) Chemical Characteristics

In view of the definition of magma-type quoted above, it is obvious that composition is the paramount factor to be considered. For the idea to have any practical value, the chemical characteristics of a magma-type must not be delimited too narrowly. The whole purpose of the scheme is to unite rocks possessing genetic affinities. That purpose would be defeated were a magma-type to be defined as precisely as a specific rock-type, for there would then be as many magma-types as rock-types. As good examples of magma-types we may refer to those which have given rise to the richly potassic suite of eruptive rocks in Uganda [1] and in Western Australia,[2] described by Holmes and Wade respectively. It does not seem necessary in either case to make further subdivision so far as magma-type is concerned, though the rocks themselves vary quite widely, and a number of new rock names have been introduced to cover them, by both authors. Yet throughout the suite richness in potassium, barium, and titanium are characteristic. In general, when defining magma-types on this basis, emphasis should be laid on the relative proportions of the characteristic components rather than upon absolute abundance: the ratio between oxides is generally a more conservative factor than the amount of any one of them.

In any one well-examined volcanic complex it may be easy to pick out the natural groupings of the rock-types as regards chemical characteristics, and thus to select and define a small number of magma-types. Thus in the Mull complex such terms as " acid- ", " sub-acid ", and " alkali- " magma-types are used, with just sufficient latitude between the several rocks included in each, as to justify the entity of the magma-type.

As soon as wider correlations are attempted with other complexes, difficulties are met with, and it becomes necessary to broaden the definitions and to limit the number of magma-types recognized. The only magmas with sufficiently uniform chemical characteristics to give them the status of world magma-types are those of basaltic composition. Basalts alone among the fine-grained eruptive rocks are sufficiently ubiquitous and sufficiently limited as regards chemical variation as to justify the belief that they are the direct representatives of one, or perhaps two, magma-types which are indeed universal. Other important rock-types such as rhyolites and trachytes are in a different category: for although they may be derived ultimately from some such parental magma-type, presumably by fractional

[1] Holmes, A., A Suite of Volcanic Rocks from South-West Uganda. . . . *Min. Mag.*, xxvi (1942), p. 197.
[2] Wade, A., The Leucite-bearing Rocks of the West Kimberley Area, Western Australia. *Quart. Journ. Geol. Soc.*, xcvi (1940), p. 39.

crystallization, yet they must be regarded as essentially the products of varying local conditions. Thus within one volcanic region all the rhyolites, for example, may be referred to one magma-type ; but the same cannot be claimed for two rhyolites occurring in different volcanic regions and possibly of different ages.

Opinion is sharply divided as to the number of fundamental basaltic magma-types. Daly, Bowen, and Wager and Deer [1] consider that the differences between basaltic types are gradational, and therefore think in terms of one world basaltic magma-type only ; but Kennedy,[2] Anderson,[3] and MacGregor [4] favour two. In effect the advocates of the latter hypothesis (of two basaltic magma-types) have taken as their starting-point the real differences that exist between two contrasted groups of basalts in Mull and elsewhere within the British Tertiary volcanic province, and have then attempted to extend the types so distinguished, and to give them the status of world-wide magma-types. In this they have used both petrological and seismological data.

In Mull three basaltic magma-types were distinguished as (i) the Plateau Type, (ii) the Non-porphyritic Central Type, and (iii) the Porphyritic Central Type respectively. Several writers including Bowen and Kennedy have pointed out that porphyritic rocks are not altogether satisfactory subjects for study in questions relating to magmas, for there is always the possibility that the phenocrysts may not be the products of normal intratelluric crystallization, but may have been added to the magma from some source extraneous to the rock under examination. When this is the case the bulk composition of the rock (plus phenocrysts) does not correspond to that of any wholly fluid magma. For the present, therefore, it is perhaps wise to exclude the Porphyritic Central Type of Mull from the discussion.

As regards chemical composition analyses " assigned to " the Plateau Type and to the Non-porphyritic Central Type have been published. Chemical distinctiveness does not appear to be well marked and it is obviously difficult to define these two magma-types in purely chemical terms. So far as nomenclature is concerned, the two terms first used applied specifically to Mull, but are they suitable in the wider concept of world magma-types ? The " Plateau Type " basalts in Mull are typically olivine-rich ; but plateau basalts, in the generally accepted sense, are notably olivine-poor lavas. Further, terms implying

[1] The petrology of the Skaergaard Intrusion . . . Eastern Greenland. *Meddel. om Grønland*, 1939, p. 323.

[2] Kennedy, W. Q., Trends of differentiation in basaltic magmas. *Amer. Journ. Sci.*, xxv (1933), p. 239.

[3] Kennedy, W. Q., and Anderson, E. M., Crustal layers and the origin of magmas. *Bull. Volc.*, 11, iii, 1938, p. 24.

[4] MacGregor, A. G., Problems of Carboniferous-Permian volcanicity in Scotland. *Proc. Geol. Soc.*, London, No. 1441, 1948, p. 72.

particular modes of eruption to magma-types are, in any case, thoroughly unsound. It is not surprising, therefore, that Kennedy[1] has substituted "Olivine-basalt Magma-Type" and "Tholeiitic Magma-Type" for the "Plateau" and "Non-Porphyritic Central" types respectively. In spite of the change, however, we regard the choice of names as unfortunate, for reasons discussed below.

(2) Mineral Composition and Texture

At this stage we do not propose to discuss the validity of the two-basalt-magma hypothesis, but only the nomenclature. It may be said, however, that the single analyses quoted by Kennedy from the Mull Memoir, as representing the chemical properties of two contrasted magma-types, are of limited value in the absence of guidance as to the degree of latitude permissible within the definitions of the two types. Is it possible to define a compositional boundary between the two types; or is there, as we suspect, a wider variation in each component than is suggested by these "assigned" analyses? In view of the undoubted difficulty of defining the contrast between two magma-types using purely chemical factors, it was perhaps natural to turn to the facts of mineral composition, and to define the magma-types in terms of mineral assemblages. Now if the name of a specific rock-type *must* be used for a Mg-rich somewhat under-saturated basaltic magma, then it is clear that the only choice—though it is indeed Hobson's choice—is "olivine-basalt". To this there are several objections. There must surely be more fundamental differences between the magma-types than those merely involving the presence or absence of olivine, for this in many cases is not so much a matter of genuine chemical distinctiveness as of cooling history. According to the well-known Bowen-Anderson effect, olivines of composition appropriate to this type of magma may separate at high temperature even from an over-saturated melt. Although normally they would be "made over" into pyroxene at some lower temperature, they may survive if the rate of cooling is too rapid for equilibrium to be achieved. It may be argued that the use of the qualifier "olivine-" before "basalt" implies "olivine-rich"; but this is not the accepted usage. It goes without saying, on the other hand, that no basalt without olivine can bear the name "olivine-basalt"; and surely no olivine-free basalt can be included in the magma-type for which the name olivine-basalt magma-type has been selected. Yet there can be little doubt that, on purely chemical grounds, some olivine-basalts overlap the composition of some basalts without olivine, and that therefore they should be referred to the same magma-type. Because of its wide-

[1] Op. cit. (1933), p. 240.

spread distribution the " olivine-basalt " magma-type is often regarded as typical of the sima in its purest and least modified form. It should therefore be well represented among the rocks erupted from the ocean floor. Hawaii may be taken as an example. Here, if anywhere, olivine-basalts should be dominant ; yet such appears not to be the case. Washington records that on Hawaii there are as many basalts without olivine as there are olivine-basalts.[1] Nevertheless they must be assigned to the one magma-type : the only alternative would be to erect a third. Finally, if the presence of olivine is taken as a hall-mark of the basalts of one magma-type, surely absence of olivine should be equally characteristic of the other (tholeiitic) magma-type. In point of fact among the rocks called " tholeiites " are many containing several per cent of olivine in the mode.

In connection with the choice of the name " tholeiite " for the second of Kennedy's magma-types, the first point to note is that fundamentally this also is a species of basalt, in the sense that it is a fine-grained basic igneous rock occurring both as lava flows and minor intrusions, and consisting of the combination plagioclase, and pyroxene, with or without olivine. It is claimed to be distinctive in regard to the subordinate rôle of olivine, the dominance of Ca-poor, Mg-rich pigeonite, a less calcic plagioclase than in typical basalts, and in the occurrence of patches of mesostasis—emphasis is laid on the last, and there is little doubt that some basic lavas are called tholeiites on this criterion alone. It must be pointed out that, in any case, this is not tholeiite in its original sense. Johannsen [2] makes but brief reference to tholeiite as a type of " melaphyre " (as defined by Rosenbusch—i.e. a porphyritic basalt of Palaeozoic age). " Melaphyre " is obsolete ; and of tholeiite Johanssen states that " the rock apparently consists of ilmenite, a little augite or hornblende, labradorite, and a little glass. The structure is intersertal, and some varieties are olivine bearing. The name is practically obsolete ".

Unfortunately the name has been revived in Britain, though redefinition has proved necessary, and the intersertal texture seems to be the one essential feature common to the several different usages current in this country at the present time. Thus while in the Mull Memoir [3] the term is applied to aphyric rocks only, Tyrrell in the Arran Memoir [4] uses it as Rosenbusch did—for porphyritic rocks. No fewer than nine named varieties of tholeiites are referred to by

[1] Washington, H. S., Petrology of the Hawaiian Islands, III : Kilauea and general petrology. *Amer. Journ. Sci.*, vi (1923), p. 338.

[2] *A Descriptive Petrography of the Igneous Rocks*, iii, 1937, p. 298.

[3] The Tertiary and post-Tertiary geology of Mull. *Mem. Geol. Surv.*, 1924, pp. 280 and 284.

[4] The geology of Arran. *Mem. Geol. Surv.*, 1928, p. 240.

Holmes [1]; but it is obvious from his description that not all of these are even basic—silica ranges from 47 to 58 per cent, and in the high-silica types quartz is an essential, not an accessory, mineral, in extreme cases reaching nearly 15 per cent!

What, then, is meant by "tholeiitic magma-type"? To find an answer one must turn to Kennedy's particular definition. The latter is surely inadequate for a magma-type of world-wide distribution. Its chemical composition is represented by a single partial analysis of one of the nine types of tholeiite referred to above.[2] Nothing is stated as to range of composition, and the author turns immediately to mineralogical and textural qualities, with emphasis, as we have already stated, on the presence of an acid interstitial residuum. In different varieties this ranges in amount from a third of the whole rock to a very small part. There is no doubt that in time this range will increase until the complete range from vitreous (tholeiitic tachylyte) to holocrystalline is on record. But a point of textural detail cannot be admitted as part of the definition of a magma-type. This magma-type may well be all that is claimed for it, but it is exceedingly ill-named. If it has the status that many believe, it deserves better of its originators than to bear an obsolescent rock-name, based on an obscure hamlet in the Saar.

(3) The Principle of Crustal Layers Applied to Magma-types

It is apparent from the above discussion that a definition of a magma-type based on precise mineralogical or chemical criteria can be valid only within one volcanic province; and that a new and broader principle should be applied in making distinction between parental basaltic magmas of world-wide distribution. Kennedy and Anderson have themselves provided the arguments in favour of our proposed solution of this problem of nomenclature. They have stated the case for the belief that the normally over-saturated basalts (of the type called tholeiites) and quartz-dolerites together with their differentiates are of such persistent and dominant occurrence in continental volcanic associations, that the presence of the impersistent layer of continental sialic rocks is essential for their formation. In fact, on geophysical grounds these authors suggest the existence of a separate (tholeiitic) layer, overlying the true sima and co-extensive with the overlying sial. From purely petrological considerations it

[1] The tholeiite dikes of the north of England (with analyses by H. F. Harwood). *Min. Mag.*, xxii (1929), p. 1.

[2] Kennedy, W. Q., Trends of differentiation in basaltic magmas. *Amer. Journ. Sci.*, xxv (1933), p. 241. The essential facts are quoted without essential alteration in Kennedy and Anderson's later Crustal Layers paper, op. cit. (1938), p. 36.

is immaterial whether this magma is derived from a distinct earth shell, or is produced by syntexis between the sima and the sialic rocks. The important point is the connection which exists between the presence of the sial and the eruption of these mainly over-saturated rocks. We believe that this would be emphasized by calling the magma-type from which the latter were derived not " tholeiitic " but " *sub-sialic* ". For the parental magma of the universally occurring basalts which are typically olivine-bearing, we suggest the name " *simatic magma-type* ". In this way attention is directed towards the genetic aspect of the problem of magma-types rather than to specific textural or mineralogical features of the rock-types which are highly variable and only incidental to the problem.

It may be objected that these proposed terms have too wide a significance and are too ill-defined. This may be so, of course, but we do not feel justified in attempting precise definition of the two magma-types, in the present state of our knowledge. The possibilities in this field still need much further research. Kennedy and Anderson have made a valuable initial contribution in pointing out the possibilities of two basaltic magma-types ; but we feel that the degree of precision hinted at by the use of the names " olivine-basalt " and " tholeiite " for these magma-types hinders rather than promotes the development of the hypothesis : at this stage the use of names of broader implication seems to be justified.

(4) Alkali and Calc-alkali Suites

We pass next to consider the use of the qualifiers " alkali " and " calc-alkali " as applied to rocks and magma-types. In rock classification and nomenclature the sense in which these terms is used is the obvious one : an *Alkali Series* includes all those igneous rocks which are characterized by a preponderance of alkali-feldspars, or in the under-saturated members, of feldspathoids, in association with coloured silicates of the appropriate composition. This category must include among its most typical members the trachytes, in which the alkali percentage is at a maximum. Only slightly less outstanding in this respect are the true (alkali-) rhyolites. In so far as the fundamental facts of mineral and chemical composition are concerned, rhyolites and trachytes are very closely related. Yet the modern tendency is to include trachytes in an " Alkali Suite ", but to put rhyolites in the " Calc-alkali Suite ", purely on petrogenetic grounds and despite their nearly identical alkalinity.

The conception of magma-types and of the production therefrom of " suites " bearing the distinctive hall mark of a common origin, is a very valuable generalization. Harker coined the term consanguinity to express this blood relationship between the several members of

such a " comagmatic assemblage ". Considerable care needs to be exercised in choosing names for these assemblages, and in our opinion the contrasting terms " alkali " and " calc-alkali " are not appropriate, and their use is causing much avoidable confusion. If " magma-type " had retained its original narrow significance, the limited range of rock-types derived therefrom would presumably have been alike in regard to alkalinity. But now that two world-wide magma-types are regarded as parental to all but a few exceptional rock-types, each of the two main suites contains such a wide variety of rocks that it is absurd to expect them to be all alike in alkalinity, or indeed in any other chemical characteristic. Thus in the suite which includes rocks with a high content of alkali-feldspars and which are thus genuine alkali rocks, the more basic and more mafic members may contain little or none of those constituents which alone make the qualifier " alkali " suitable.

In the so-called " alkali series " of Kennedy and MacGregor, olivine-basalt is included, and indeed fills a vital rôle. Yet no rock is more typically calc-alkaline, and surely in view of the overwhelming predominance of basalt among the world's lavas, " alkali " is the last term to apply to the magma which it represents. In spite of this, however, this world-wide magma-type has acquired the description " alkali-olivine-basalt " or " alkali-basalt ", not by reason of any intrinsic compositional feature, but because it is thought possible that it may, in certain circumstances, give rise to alkali-rich trachytes. This is bound to cause confusion in the minds of students who would naturally think that a rock-type such as nepheline- or leucite-tephrite or basanite is involved, for they are in fact the only types of lava which may properly bear these names.

The position is equally unsatisfactory in regard to the second world-wide magma-type, which has acquired the description " calc-alkali tholeiitic ". Holmes has aptly summarized the characters of tholeiites as involving a basaltic crystalline framework enclosing the characteristic mesostasis. The latter is believed to be of the same composition as the graphically intergrown alkali-feldspar and quartz which is so distinctive of quartz-dolerites of the Whin Sill and Ratho types, for example. As tholeiite and quartz-dolerite, therefore, consist of basalt plus an acid alkaline residuum, in what sense can they be described as " strongly calc-alkaline " ? It has been stated that the residuum from tholeiite is calc-alkaline, but in fact it is richer in total alkalies than the residuum from olivine-basalt. The latter is stated by contrast to be alkaline, but it is far richer in calcium and poorer in total alkalies than the tholeiitic residuum. In erecting an " alkali suite " in which the dominant members are calc-alkaline, and a " calc-alkali " suite which includes important alkaline rock-types,

are we not getting dangerously close to the Humpty-Dumpty attitude of mind towards the meanings of the words we use ?

In any case, these adjectives seem superfluous. If two or more suites of rock types were developed from a single magma-type, it would be necessary to distinguish between them, and qualifiers denoting different degrees of alkalinity would be eminently suitable for the purpose. In the present case, however, we are dealing with two suites developed from two contrasting magma-types, and therefore the need for qualifiers does not arise. Whatever names are ultimately adopted for the two magma-types should be equally applicable to the suites of rock-types evolved from them. If our suggestion proves acceptable, the *simatic suite* comprises the olivine-basalt–trachyte assemblage produced by differentiation from the deeper-seated simatic basalt layer ; while the *sub-sialic suite* comprises the tholeiite-rhyolite range of rock types which have originated in the higher (tholeiitic) layer underlying the continental land-masses.

Overturned Rhythmic Banding in the Huntly Gabbro of Aberdeenshire

By R. M. Shackleton

(PLATE XXI)

In a recent letter to this journal, Stewart and Wager (1947) record the occurrence of rhythmic banding in the Cuillin gabbro of Skye. Apparently, before this the only described British example of rhythmic banding was in the Belhelvie Complex of Aberdeenshire (Stewart, 1946). In view of the interest in these structures aroused by Wager and Deer's vivid and illuminating account of the Skaergaard Complex of East Greenland (Wager and Deer, 1939), a preliminary note on a more accessible occurrence where rhythmic banding is very beautifully displayed, in excellent quarry sections, seems desirable. This occurrence is in the Huntly complex of Aberdeenshire.

The Huntly complex was described by Read (1923) in the Banff, Huntly and Turriff Memoir; he noted the occurrence of banded troctolites and related rocks near the western margin of the mass. More recently, in welcoming Stewart's account of the Belhelvie complex, Read remarked on the implications for the comparable Huntly mass, but he foresaw formidable tectonic difficulties if the banding there were to be interpreted as a sedimentation-layering.

Since the memoir was written, a large new quarry has been opened at Bin Hill, about 3 miles from Huntly, just above the road to Keith. In this quarry the banded rocks are magnificently displayed. The bands dip consistently westwards at about 70°. They range in thickness from many feet down to less than an inch, and are conspicuous owing to the varying proportion of plagioclase to olivine and pyroxene. Some layers are anorthositic, some consist almost wholly of olivine and serpentine formed from it.

Closer examination of the bands shows that many are graded from melanocratic to anorthositic. The grading in such bands is consistently in one sense and there is often a sharp contact between the most melanocratic part of one such band and the most felspathic part of the next (see Pl. XXI). The phenomenon is so strikingly similar to that described as rhythmic banding by Wager and Deer (1939, p. 37) that its similar origin can hardly be doubted, especially as the textures seen in slice are also very similar in the two cases. The parallel arrangement of the platy felspars, for which the term igneous lamination was used (*ibid.*, p. 37), is also well seen at Bin Hill. The only conceivable alternative origin is by replacement of sediments with graded bedding and this is not possible at Skaergaard, where the enclosing rocks are basalts, nor is the Huntly evidence, taken by itself, consistent with such a theory.

A mile or so north-west of the Bin Hill Quarry there is another one (Sinsharnie Quarry) by the same road, in which rhythmic banding is again well seen in a troctolitic rock (Pl. XXI). In both these quarries, and in other exposures in their vicinity, the strike of the banding is regular, approximately parallel to the western contact of the Huntly mass. In both cases, moreover, the attitude of the rhythmic bands indicates clearly that their base is to the west. They therefore young eastwards, and are overturned. The western contact of the Huntly mass therefore presumably represents its floor ; this is also indicated by the general sequence of rock types in the mass with ultrabasic rocks mapped near the western contact, and by the occurrence of the rhythmic banding at the western side, for rhythmic banding is usually confined to the lower parts of a layered complex.

To account for the fact that the rhythmic banding is now overturned, it might be argued that it was developed elsewhere and carried more or less intact into its present position during intrusion ; or that the mushy layers were disturbed after their formation by movements of the magma. The regularity of the bands, their parallelism to the main contact, and the comparable nature of the phenomena here and in other layered complexes, tell against any such views. The overturning of the layers, which must originally have had a gentle dip, clearly took place when the rocks were rigid, not mushy, and is therefore presumably tectonic. A similar conclusion was reached for Belhelvie by Stewart (1946), although there the banding was not actually overturned but was pushed up from the west to a nearly vertical attitude.

As regards the relation of the Huntly mass to the surrounding Dalradian rocks, we find that the mass itself is, broadly speaking, concordant, and was presumably a sheet-like injection of magma, although both the mapping and petrology indicate that considerable masses of the schists were assimilated into the magma. Read holds that the injection of this and other related " younger basic " rocks of north-east Scotland occurred after the main folding of the region, as well as later than the metamorphism. The overturning of the rhythmic banding at Huntly and its upturning at Belhelvie are against this view, and the mapped disposition of the different members of the Huntly complex also suggests at least a notable dip of the whole mass. It is significant that the Dalradian rocks themselves have been shown to young eastwards towards the centre of the Banff syncline (Read, 1936), and that, in the districts around the Huntly mass, the Dalradian rocks are often overturned eastwards. It is therefore suggested that the Banff syncline, and some at least of the eastward overfolding in the Dalradian rocks, is later than the intrusion of the younger basic rocks of north-east Scotland.

As to the date of these movements, all that can be said now is that

they must be later than the general metamorphism of the Dalradian rocks of the region and they are clearly earlier than the gently dipping beds of supposed Middle Old Red Sandstone age. One may perhaps compare the Banff syncline with such post-metamorphic structures as the Cowal and Islay anticlines and the Loch Awe syncline.

EXPLANATION OF PLATE XXI

RHYTHMIC BANDING IN TROCTOLITES FROM THE HUNTLY COMPLEX. Above, specimen from Bin Hill Quarry; below, one from Sinsharnie quarry. Both are oriented as they would be seen looking northwards along the strike of the banding. Plagioclase appears white, olivine black. There is a little pyroxene in the Bin Hill Rock.

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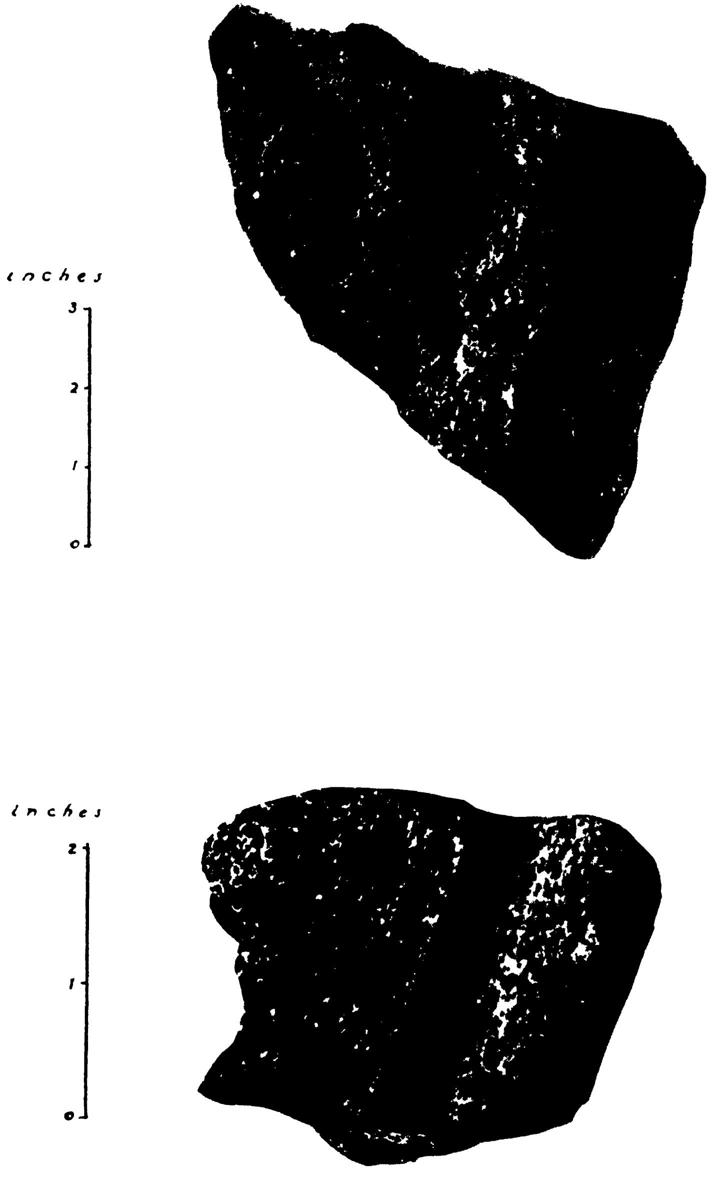

Rhythmic Banding in Troctolites from the Huntly Complex.

The Eighteenth Session of the International Geological Congress, Great Britain, 1948

By A. J. Butler, General Secretary

General

THE Eighteenth Session of the International Geological Congress was the first session in Great Britain for sixty years ; and because of wartime interruption the interval between the Seventeenth and Eighteenth Sessions was longer than that between any previous consecutive sessions. The Session therefore presented a special opportunity for the renewal of international discussion and for the demonstration of classic and recent research in Britain.

In 1946, when the decision to hold the Eighteenth Session in 1948 was taken, it was reasonably expected that international conditions would be a good deal easier by 1948 than has proved to be the case. It is pleasing to record that there was, despite present economic and political hindrances, a very large and widely representative attendance. The total membership, including non-attending members, was over 1,760. The actual attendance at the Session, including some 250 relatives, was about 1,600 ; of this total attendance about 900 were visitors from abroad. Seventy-six countries were represented. Sixty-four Governments and 360 universities, societies, and institutions sent official delegates to the Session.

The Headquarters and Registry of the Congress, in the Geological Survey and Museum, opened on 3rd August, and the first of the nineteen long excursions before the Session in London left on 6th August. The weather was not favourable either for these or for the group of eighteen post-Session long excursions, which lasted until 19th September ; but there is no doubt, from appreciation expressed by the overseas geologists who predominated in the parties, that the programme of long and short excursions was a success, and that the efforts of the 250 British geologists who acted as organizers and leaders were well worth while.

At the formal opening of the Session on 25th August, Professor H. H. Read was elected President of the Session. Viscount Addison welcomed the General Assembly on behalf of H.M. Government and Sir John Anderson spoke on behalf of the General Organizing Committee. During the following week there was a very full programme of meetings and receptions. Special addresses on the Structural History of Britain were given to the General Assembly by Professor O. T. Jones and Sir Edward Bailey. Two other items of great general interest were colour films of the Mexican volcano Paricutin, presented by Dr. F. H. Pough and Dr. J. G. Reyna, and of the Virunga Volcanoes, presented by Professor T. W. Gevers. The Council of the Congress, the delibera-

tive body composed of the official delegates of Governments and institutions, dealt under the chairmanship of Professor Read with a long agenda which included restoration of various international Commissions of the Congress. At the Sectional Meetings over 200 individual papers, out of 350 which had been offered, were presented and discussed. Receptions to the whole Congress were given at Lancaster House by H.M. Government on 25th August, and at Burlington House by the Geological Society on 31st August. Official delegates and their relatives were received by the Vice-Chancellor of the University of London at the Senate House on 30th August ; and there were many other receptions and entertainments.

The attendance at all the meetings and receptions was impressively large. It was clear that members were pleased to take every opportunity of formal or informal discussion and contact with colleagues from other countries.

A full account of all the proceedings of the Session will be contained in the eventual Report of the Session, but this cannot be ready for at least a year.

A chief purpose of the present note is to make known, in advance of the full Report, some of the more important decisions of the Council of the Congress. The next issue of the *Geological Magazine* will contain summaries of the proceedings of the Sectional Meetings, of meetings on the Geology and Mineralogy of Clays, and of meetings of the Association of African Geological Surveys and the International Palaeontological Union.

Council and Commissions

International Union of Geology

One of the major items on the agenda of the Council was the question of the desirability of forming an International Union of Geology, to become affiliated to the International Council of Scientific Unions. The Natural Sciences Division of UNESCO, which has arranged liaison with the International Council and its constituent scientific Unions, had expressed its hope that such a Union might be formed ; and geologists from several western European countries had expressed a wish for discussion. Dr. Joseph Needham, lately head of the Natural Sciences Division of UNESCO, was present at the Council's discussion of this item, and explained that UNESCO was anxious that there should be some permanent internationally representative executive body from which UNESCO might seek geological advice. In discussion it was clear that most delegations wished to aid UNESCO as far as possible, but that a substantial number were not otherwise convinced that the promotion of a Union was necessary or desirable, and feared that it might possibly complicate the successful organization of future

sessions of the Congress. It was finally agreed that a decision on the formation of an International Union of Geology be postponed until the next session of the Congress ; and that meanwhile the Bureau of the Congress, composed of the Heads of all Government delegations, shall be prepared to advise UNESCO on geological matters. Dr. Needham indicated that this would be a satisfactory interim arrangement from point of view of UNESCO.

Russian as an Official Language

The Council had also before it a proposal, transmitted from the Seventeenth Session in Moscow, that Russian should be an official language of the Congress in addition to the existing official languages—English, French, German, Italian, and Spanish. The proposal was accepted by a large majority. At the same time members expressed a hope for improved communication and interchange of publications between the geologists of U.S.S.R. and those in other countries.

National Geological Reserves

At the proposal of Dr. G. F. Herbert Smith, on behalf of the Society for the Promotion of Native Reserves, it was agreed to recommend to all Governments represented at the Congress that, in any country where suitable action has not already been taken, lists of geological sites and districts of outstanding scientific importance shall be compiled (as has been done in England and Wales at the instigation of the Nature Reserves Investigation Committee), and that legislative measures shall be taken for safeguarding these sites and securing access to them.

Abstracts of Geological Papers

Another question of some general importance was that of the effectiveness of present arrangements for the preparation and publication of abstracts of geological papers. Several journals of abstracts were discontinued during the war and have not yet been revived. Following a recommendation from its permanent *Commission on Authors' Abstracts*, of which Dr. M. I. Goldman (U.S.A.) is President and M. F. Blondel (France) is Secretary, the Council agreed strongly to recommend to all editors and publishers of geological journals that a concise but adequate abstract shall be prepared by each contributor and printed at the head of his paper, in one of the official languages of the Congress. It may eventually be possible to arrange for the assembly of all such abstracts in some central journal.

Commissions of the Congress

During the long and largely wartime interval since the previous Session the work of many of the permanent Commissions of the

Congress had inevitably been suspended. The state of each Commission was reviewed during the Session. Among those which were reconstituted were the following :—

The Commission on the Crust of the Earth, of which Professor P. Fourmarier (Belgium) is President and Professor E. Wegmann (Switzerland) is Secretary ; this will have the immediate object of preparing a standard lexicon of tectonic terminology, based on the work of Heim and de Margerie, and a standard scheme of tectonic symbols for geological maps.

The Commission on the Lexicon of Stratigraphy.—This has the purpose of preparing for each continent a dictionary of stratigraphical terms, and a volume for Africa has already been published ; Sir Edward Bailey is the new President.

The Commission on the Gondwana (Karroo) System.—Despite wartime difficulties, Dr. S. H. Haughton (South Africa), the Secretary of this commission, was able to present, following a recommendation made at the Seventeenth Session, a substantial report summarizing evidence of climatic conditions in " Gondwanaland " during the Carboniferous, Permian, and Triassic periods. Dr. Haughton becomes President of the reconstituted Commission, and Dr. Curt Teichert, of Australia, has been invited to become Secretary.

The Commission for the International Geological Map of the World and the *Commission for the International Geological Map of Europe.*—In reconstituting these two Commissions it was arranged that the Directors of appropriate national geological surveys shall be *ex officio* members. Publication of the maps will be resumed as soon as conditions permit.

The Commission for the International Geological Map of Africa.—This is a thriving body, which has an executive sub-commission, l'Association des Services Géologiques Africains, whose President is Dr. F. Dixey and Secretary is M. F. Blondel, of Paris. Good progress in the preparation and publication of the nine sheets of a 1 : 5,000,000 map of the African continent was reported, and it is hoped that the map will be completed before the next Session of the Congress. The Association des Services Géologiques Africains organized during the recent Session a most successful series of open meetings at which syntheses of geological research in Africa during the last decade were presented.

It was decided not to revive the *Commission on Geophysics and Geothermics*, and the *Commission on Petrology, Mineralogy, and Geochemistry*. The question of restoring the *Commission on the Determination of Geological Age by Radioactive Methods* was postponed until the next session in view of present restrictions on the international exchange of information concerning radioactivity.

Certain new Commissions were set up at the Eighteenth Session. One of these was a temporary *Commission on the Pliocene-Pleistocene Boundary*, with Professor W. B. R. King as President and Dr. K. P. Oakley as Secretary, which recommended that this boundary be based on changes in marine faunas, and selected Italy as the type area, with the marine Calabrian formation and its terrestrial equivalent the Villafranchian formation as the basal member of the Pleistocene System. The Council discussed a suggestion by Netherlands geologists that the beginning of pre-boreal conditions be accepted as marking the Pleistocene-Holocene boundary, but decided to recommend this suggestion for the consideration of botanists, archaeologists, and geologists without accepting it as a final definition. A permanent *Commission on Meteorites* was set up at the suggestion of Professor W. Wahl, of Finland, who becomes its President, to promote the study of meteorites and in particular their accurate chemical analysis. A permanent *Commission for the Preparation of a World Physiographic Map* was instituted after representatives of fifteen countries had met on the initiative of Dr. L. L. Ray, of Washington. Dr. Ray is Chairman and Professor F. M. Fryxell, of Illinois, is Secretary. The Commission will promote the preparation of an international physiographic province map on the pattern of that already prepared for U.S.A. by the United States Geological Survey.

The Spendiarov Prize.—The only prize awarded by the Congress is the Spendiarov Prize, endowed at the Seventh Session in Russia in 1897. The Soviet delegation proposed that the Spendiarov Prize for the Eighteenth Session be awarded to a British geologist, and the standing Commission for the prize chose Professor L. R. Wager, of Durham, as the recipient. Professor V. V. Belousov, Head of the Soviet delegation, addressing Professor Wager at the Final Meeting of the General Assembly on 1st September, paid tribute to Professor Wager's research in the Himalayas and in Greenland.

The Nineteenth Session of the Congress

One of the most interesting items considered by each Session of the Congress is its future place of assembly. Two attractive invitations were offered at the Eighteenth Session. Professor L. Lutaud, on behalf of the Government of France, presented an invitation to hold the Nineteenth Session in North Africa in 1952, with headquarters in Algiers, and Dr. D. M. Wadia presented an invitation from the Government of India to hold the next Session in India, early in the same year. The Congress decided to accept the invitation to Algiers, but expressed its gratitude for both invitations, and the hope that the invitation to India may be renewed at the Nineteenth Session.

CORRESPONDENCE

A GEOLOGICAL 2½-INCH MAP

SIR,—I would join Mr. Evans [1] in welcoming the new Ordnance Survey 2½-inch map [2] and recommending geological use of the National Grid. I was wondering how best to advocate consideration of similar scale and sheet maps by the Geological Survey when the publication of Professor Linton's paper to Section C, 1947,[3] came to hand. As that considers many aspects of the problem I would now ask in your pages to review briefly the case for a new 1/25,000 geological map of Britain.

(1) Comparison of different national geological maps shows that in some cartographic respects ours now fall behind the best. This would be widely appreciated if students had more opportunity to study maps from different countries.

(2) The present time, when so much of the old has been destroyed, and when so much new is coming from the Ordnance Survey, is surely opportune for such reconsideration.

(3) A scale of 2½ inches to one mile would show most of the detail now published or recorded on 6-inch maps. Such a uniform series, with carefully reconsidered conventions, would make generally available a wide and useful range of palaeontological, petrological, structural, and economic detail. Germany [4] and Switzerland, for example, have successfully employed this scale.

(4) Each sheet is 10 by 10 km. and constitutes four quarter sheets of the projected national 6-inch topographical series. Covering such an area, each sheet could be published within a short time of field work without waiting to complete 12 by 18 square miles, or more in Scotland.

(5) The cost of publication of about 2,500 new sheets would be spread over a long time and would be partly offset by suspending publication of 6-inch geological maps, copies of which could still be provided when necessary.

(6) The position of the 1-inch geological "New Series" is a different question and is not hereby attacked.

(7) The same considerations apply, and indeed more readily, to individual maps published in journals.

W. B. HARLAND.

SEDGWICK MUSEUM,
CAMBRIDGE.
19th August, 1948.

GLACIAL SECTIONS IN THE WELSH BORDERLAND

SIR,—I should be grateful if you would allow me to draw the attention of your readers to two extensive gravel pits revealing very interesting sections in glacial deposits along the Welsh Border. The first, at Yatton, near Aymestry, is in outwash gravel and delta sands deposited from the western lateral moraine of the Wye glacier into the glacial lake Wigmore. The second, at Stretton Sugwas, near Hereford, is in a retreat moraine of the same glacier. The progress of working in this pit is almost daily revealing fresh sections of most interesting structures due to pressure, deposition, melting, etc.

With Professor Wooldridge I had the pleasure of showing a party of the International Congress over these pits in August and their enthusiasm, especially that of the Scandinavian glaciologists, was unbounded. Small workings existed on these sites twenty years ago when I studied the region

[1] *Geol. Mag.*, lxxxv, p. 242.
[2] *Ibid.*, p. 183.
[3] "The Ideal Geological Map," *The Advancement of Science*, v, no. 18, p. 141, 1948.
[4] *Geol. Mag.*, lxxxiv, p. 171.

with Dr. Dwerryhouse, but nothing comparable with the scale on which the gravel and concrete hunters work to-day. The dimensions of the exposure and the rapid rate of working provide an excellent opportunity for studying structures only rarely to be seen in this country, and make it imperative that some competent glaciologist should watch the progress of the work and record the structures revealed in the developing face.

A. AUSTIN MILLER.

DEPARTMENT OF GEOGRAPHY,
THE UNIVERSITY,
READING.
6th September, 1948.

BATHONELLA AND *VIVIPARUS*

SIR,—Dr. Cox has put forward arguments in favour of regarding *Valvata comes* from the Viviparus Marl of Oxfordshire as a marine species of another genus. Dr. Yen contends that the *Viviparus* itself (*V. langtonensis*) is a marine species of his genus *Bathonella*. It therefore seems desirable to place on record the occurrence of two forms from the Viviparus Marl that are more certainly of freshwater origin. From samples collected at both Castle Barn and Sharp's Hill, the Marl has yielded an undescribed species of the ostracod genus *Metacypris*, and the gyrogonites of a Charophyte. Recent Charophyta are exclusively freshwater. Recent *Metacypris* inhabit the almost freshwater broads of the Fenland. Both Charophytes and *Metacypris* are abundant associates of *Viviparus* and *Valvata* in the Cherty Freshwater Beds of the Middle Purbeck of Dorset. At the same time, it must be admitted that I have also found gyrogonites (but not *Metacypris*) in certain members of the underlying Sharp's Hill Beds usually regarded as marine.

P. C. SYLVESTER BRADLEY.

DEPARTMENT OF GEOLOGY,
ST. GEORGE'S SQUARE,
SHEFFIELD, 1.
2nd October, 1948.

BATHONIAN AMMONITES

SIR,—I am anxious to examine for a monograph in preparation all ammonites from the Fuller's Earth, Fuller's Earth Rock, Stonesfield or Cotswold Slates, Great Oolite, Forest Marble, and Cornbrash. If any collector or curator will send me material on loan it will be gratefully acknowledged and carefully returned as soon as examined. Ammonites are so rare in some of these formations that even a fragment may be something new and stratigraphically important if accurately localized.

W. J. ARKELL.

SEDGWICK MUSEUM,
CAMBRIDGE.
11th October, 1948.

EAST ANGLIAN DRIFTS

SIR,—Mr. Baden Powell's paper on East Anglian drifts [1] adds greatly to our knowledge : his data, which must have cost much time and labour to amass, will, I feel sure, be of permanent value. Nor would I quarrel with his sequence, if the Hoxne beds could be placed on top of all, not in the middle. But though in accord with current practice, the four glaciations claimed, with their appropriate intervals, can, and should, be challenged.

[1] D. F. W. Baden Powell. The Chalky Boulder Clays of Norfolk and Suffolk. *Geol. Mag.*, Oct., 1948, pp. 279–296.

Otherwise opinion, which has advanced greatly since W. B. Wright's "certainly two, probably three, possibly four", may petrify into dogma.

Joining an International Congress excursion, I recently saw some leading sections, taking two days off to re-examine the more critical ones on the coast, at Corton and Happisburgh. Little enough for a region so intensively worked over as this, but then no observations ever seem to have been made there on what I cannot help feeling are key matters, the purely physical evidences for or against retreat and re-advance. Orthodoxy has always neglected such things, to its detriment north of the Wash. Discoveries, then, were likely in East Anglia, and might be instructive. So, indeed, it proved.

This is no place to detail the evidence, but, in brief, only the local basement beds, such as the Cromer Tills on the Norfolk coast, or the Lowestoft (Chalky-Jurassic) Till around Ipswich, showed that disturbance and incorporation which one expects to see when a great ice-sheet moves forward over open country, whether frozen or not. Elsewhere the under-contacts of higher tills, whether at Corton or Happisburgh, and also a clay-strip within the Corton Beds, showed roof falls on to sands gathering below, thereby betraying the undermelt of a composite ice-sheet. Confirmation was given by the supposed lake silts amongst the Cromer Tills at Happisburgh, which are shear-clays (once the banded dirts of an ice-sheet) beyond all doubt. There was no sign even of oscillation, much less re-advance, anywhere. As for the highest till, the Hunstanton Brown Clay, few, I think, would doubt its correspondence with the Hessle of the north : both in position and content the two agree, and the flats of The Wash alone divide them. My reasons for denying a separate glaciation to the Hessle Clay have recently been published,[1] and with that there remains no motive for regarding the whole East Anglian sequence as other than monoglacial, though with changes of direction, as in the north country too. When seeking further glaciations in Britain we shall have to content ourselves with the little "Moraine" or "Highland" episode (or episodes), affecting only the mountain tracts.

A word about Hoxne, which interested me greatly as the site of that rare thing, a true lacustrine deposit. No doubt it has been put in the heart of the series because it was thought that East Anglia held a full Continental sequence of glaciations, and the flint implements (as I would agree) pointed to a midway position therein. But Clement Reid had sound reasons for making Hoxne "post-Glacial", using that term in a purely English sense. The thin stony cover which has appeared since his time, as the workings got into higher ground, I certainly regard as a solifluxion wash, slight though the surface relief is hereabouts. Though I would date the Hoxne lake after all the tills, still, on a wider view, that only means that it came after the Saale, chief of the four North European glaciations, and seemingly *our only one in Britain* (away from the Highlands and their counterparts). The two cold periods at Hoxne are periglacial features associated with European re-advances not seen in this country save in the mountains. The Thames Valley evidence, so ably summarized by Messrs. King and Oakley,[2] gives the story in full, starting with the Lower Gravel of the High Terrace, after our main glaciation had ended. British Interglacial deposits, then, are to be sought in what an older generation would call post-Glacial sediments, and not within the tills, even at Kirmington.

R. G. CARRUTHERS.

HIGH BARN,
STOCKSFIELD-ON-TYNE.
14th October, 1948.

[1] *Proc. Yorks. Geol. Soc.*, xxvii (1948), 149–154 and 164. This address, the first part of which appeared in 1947, gives my matured opinion on Glacial Drifts in general.

[2] W. B. R. King and K. P Oakley. The Pleistocene Succession in the Lower Part of the Thames Valley. *Proc. Prehist. Soc.*, 1936, 52–76. (The glacial correlations offered were necessarily those current at the time.)

REVIEWS

IGNEOUS ROCKS AND MINERALS. By ERNEST E. WAHLSTROM. ix + 367. Illustrated. New York: John Wiley and Sons, Inc.; London: Chapman and Hall, Ltd. 1947. Price 33*s*.

Igneous Rocks and Minerals is intended for the use of beginners and at the same time to be of value to more advanced students. Part I deals with igneous minerals and includes chapters on the optical examination of rock-forming minerals, supplementary methods for examining minerals, descriptions of the individual minerals, and useful tables for mineral identification. The descriptions of the minerals are clear and concise and there is no attempt to bemuse the beginner by the inclusion of the rarer species. It is a pity, however, that no mention is made of the crystal structure of the commoner minerals. This portion of the book is well-illustrated by line drawings and photographs, though the definition of some of the latter is not as good as it might be. Part II deals with igneous rocks and comprises chapters on their geological occurrence, structure, texture, colour, and alteration; chemical composition and classification (including an account of the norm and methods of plotting rock analyses), mineral composition and classification, descriptions of igneous rocks, and a final chapter on the microscopic identification of igneous rocks.

The author adopts a semi-quantitative mineralogical classification of igneous rocks and describes them under families, such as the granite-rhyolite family, the tonalite-dacite family, etc. Many petrographers will not agree with the statement on p. 283 that "adamellite embraces both quartz monzonite and granodiorite".

The reviewer found this descriptive portion of the text disappointing. In particular, far too many rock names are given—many of them names which should be buried in oblivion, and more illustrations of typical thin sections of the commoner rock types would have been helpful to the student.

S. R. N.

REPORT ON THE GEOLOGY OF BASUTOLAND. By G. M. STOCKLEY. pp. vii + 114, with 3 plates, 40 photographs, and a coloured geological map; published by the Basutoland Government, Maseru, 1947. Price 10*s*.

This curious enclave of 11,700 square miles, within the Union of South Africa, but not of it, is essentially a native reserve. The inhabitants have always shown a strong aversion to prospecting for minerals within its bounds, and obviously the real object of the geological survey described in this Report was to show that there are no minerals of prospective economic value, and thus to protect the Basutos from disturbance of their normal way of life. There have been in circulation wild stories of discoveries of diamonds, based on the presence of kimberlite pipes, but so far all the supposed diamonds have turned out to be quartz crystals.

The author of this Report was seconded from the Geological Survey of Tanganyika at the request of the Basutoland Government for two years, 1938–40. In general terms the geology of the country is stratigraphically very simple. Fortunately, there was already a good topographical map of this mountainous country, which is bounded on the east by the highest part of the Drakensberg, up to over 10,000 feet, and three high peneplains have been traced. The formations present range fromUpper Beaufort to Stormberg (Drakensberg Lavas, 4,500 feet thick) with Karroo dolerite dykes and sills, and kimberlite intrusions. There are also high-level gravels, with alluvium and aeolian sands.

The general structure is a basin, which has undergone slight folding along two sets of axes with the usual African strike N.W.–S.E. and N.E.–S.W. while there are few important faults. This is, of course, the type area for the Drakensberg or Stormberg lavas, which were of fissure type and numerous necks have been found. The Karroo dolerites are generally interpreted as

a later intrusive phase of the same activity, which is one of the greatest eruptive events of the world's history. The kimberlite intrusions, like those in the rest of South Africa, are probably Cretaceous.

The natural soils of the country are mostly good, but much overcropped and overstocked, and unfortunately Basutoland has become a sort of type-area for soil erosion and formation of dongas. Trees are very scarce and extensive tree-planting would help much to mitigate this trouble which has led, in certain places, to the drying up of springs.

R. H. R.

THE PERMO-TRIASSIC FORMATIONS, A WORLD-REVIEW. By R. L. SHERLOCK, D.Sc., A.R.C.S., F.G.S. Hutchinson's Scientific and Technical Publications, London. No date (1947 or 1948), 31*s.* 6*d.*

In this important world-wide review, Dr. Sherlock returns to the problem of the classification of the Permo-Trias and the status of the Permian System. The problem is one that is bound to arise whenever major stratigraphical boundaries are defined in places where incomplete sequences exist, and where of necessity the succession of rocks fails to record some part of geological time. The Permian and Trias, based as they were upon continental developments in a region that had been undergoing major earth-movements at the time, present the problem in a particularly aggravated form.

Dr. Sherlock's main contentions are that the rocks usually assigned to the Permian can always be better treated either as Carboniferous or as Trias, and that there is no justification for perpetuating the Permian as a " System ". Much of the book is devoted to a detailed conspectus of the Permo-Trias and " Permo-Carboniferous " in both marine and continental developments. With this in view he discusses the evidence that the local stratigraphy affords wherever the appropriate formations are known all over the world. These chapters on stratigraphy and classification occupy the major part of the book and supply the evidence which is regarded as necessary to prove his contention. There is, however, little discussion of the general principles involved or guide posts to point to the conclusions which the evidence is meant to substantiate. Certainly great concentration is needed to follow the thread of the main arguments through the baffling maze of detail drawn from the world-literature which he abstracts. The assembly of all this scattered information must have been a colossal undertaking, and students of this problem are in debt to Dr. Sherlock for bringing between two covers the vast and scattered literature related to it. His list of authors and titles alone fills 18 pages !

The main discussion is preceded by valuable chapters on " the origin of Red Beds ", " the geography of the Permo-Trias ", " Palaeontology ", and " Economic Products ". Dr. Sherlock is a convert to the Wegener Hypothesis of continental drift, especially as modified by du Toit, and he stresses the many features of late-Carboniferous, Permian, and Triassic stratigraphy that accord with Wegener's ideas of the distribution of the continents at that period in Earth history.

L. J. W.

ROCKS AND ROCK MINERALS. By L. V. PIRSSON. Third edition, revised by Adolph Knopf, 1947. vii + 349 pages, 108 illustrations. John Wiley and Sons, New York ; Chapman and Hall, London. 24*s.*

The third edition of this work by the late L. V. Pirsson appears after a lapse of twenty-two years and has been revised by Adolph Knopf. Not only has the original text been simplified, condensed, and brought up to date, but portions, such as the chapters on sedimentary rocks, have been rewrittent For those unfamiliar with this book, it should be emphasized that it is concerned only with the megascopic features of rock-forming minerals and rocks and does not deal with their microscopic characters.

S. R. N.

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